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Evaluation and understanding of Playware Technology – trials with playful balance training.

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Evaluation and understanding of Playware Technology – trials with playful balance training

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Evaluation and understanding of Playware Technology – trials with playful balance training

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Summary

This thesis is an investigation of the new technologies used to motivate elderly people in a playful manner to do physical exercises, which can improve their physical health and, thus, prevent accidents. For example, fall accidents caused by falling are widespread among older adults. The thesis further studies exactly how digital technology and games can create play for the elderly, with the ambition of reaching a more substantiated understanding of this process that could then lead to a better and more calculated design of new products.

The technology in focus, “MOTO Tiles”, is an example of “playware”, which is defined as hardware or software that aims to initiate play and playful experiences among its users. The thesis evaluates MOTO tiles as an example of a relatively new area of research, Games for Health, where digital games are seen as tools for the creation of health-promoting activities.

The thesis starts with a presentation of the results of two different pilot trials done with the MOTO tiles technology which showed remarkable development among the elderly, particularly regarding balance. It further contextualizes MOTO tiles in the research area of "games for health" by an account of research done in this area, including the sub-area of “exergames”, which are games that require the user to be physically active in order to play. This account points out that the research hitherto completed is inadequate with regards to scientific validity. The review of randomized controlled trials (RCT) done in the area of exergames shows that there is a need for more studies, and for studies with a higher methodological quality.

Based on the knowledge gained in the pilot studies and the review of the area of exergames, the author of this thesis analyzes and presents how RCTs are done,

as well as exploring how to secure studies of high methodological quality. The knowledge gained from this analysis is then used to plan and conduct an RCT on the MOTO tiles with elderly people in the age range from 70 years and above.

The findings from the RCT show that it is possible to do a study of high methodological quality, but it also points out problems that are partly to do with the age group, including the problem of missing data due to, for example, sudden illness, which is more common among elderly. None the less, the findings of the study showed one primary outcome that was significant (an increase of 22% in score in the test “Chair Stand”) and another that had indications that there could be an important clinical finding (a decrease of 12% in score in the test “Timed Up & Go”), while one was unaffected (no difference in the test “6 Minutes Walking Test”). The author concludes that more studies are still needed and that higher power of the studies should be considered or meta-analysis on several trials combined.

The trial additionally confirms the findings from the pilot tests and shows that the participants saw statistically significant improvements on the balance score (“Line Walk” or “Tandem Walk”) with an impressive increase of 149% in score after adjusting for the outlier.

Besides the physical tests, the participants answered a questionnaire, and here the findings showed that the vast majority of the participants enjoyed the training and wanted to continue using the MOTO tiles. Over half also indicated that they felt better and 75% indicated that they had improved physically. This shows that playware such as the MOTO tiles can promote health and, not least, that this can be done in a playful and thus, motivational manner.

Taking these findings as the point of departure, the thesis further investigates how the MOTO tiles as an example of playware and exergames created play among the users. This investigation begins with a presentation of the concept of play, based on the philosophy of play that is the foundation of modern game research. Play is here understood as something we humans engage in for nothing else than the sake of the enjoyment it brings, or, as it is formulated: The purpose of play is play itself.

From this understanding, the thesis goes on to present we in play we have a special attitude towards the world, and this frames our understanding of actions done when we are in what we call the "state of play". Further, the thesis gives an account of an important finding in playware research, that in order to get into the state of play we use “play tools”, such as games, toys etc. This finding is further developed in the thesis by applying the Actor Network Theory (ANT) as a framework for analysis, by which the author reaches a new understanding of games as “actors” which encourage their players to act in certain prescribed ways, with the goal of bringing them into the state of play. This brings a new perspective on games and gives a framework to understand how play tools work.

Developing on these findings, the thesis then presents the notion of "play dynamics" that is, dynamics, which play tools make use of to bring players into the state of play. Examples of such dynamics are presented, and the thesis points to the need to further develop our understanding of play dynamics, the different types of dynamics and how they work together to create new dynamics and effects.

Resumé

Resume Afhandlingen er en undersøgelse af ny teknologi, der på en legende måde motivere ældre til at udføre fysiske øvelser, som kan forbedre deres fysiske sundhed og dermed forebygge ulykker, som for eksempel faldulykker, der er udbredt blandt ældre voksne. Afhandlingen undersøger, hvordan digital teknologi og spil kan skabe leg med en ambition om at nå frem til en videnskabelig begrundet forståelse, der kan føre til bedre og mere velbegrundede design af nye playware produkter.

"MOTO"-fliserne er det teknologiske fokus i afhandlingen. De er et eksempel på "playware", der er defineret som hardware og software, som har til formål at producere leg og legende oplevelser blandt sine brugere. Afhandlingen undersøger MOTO-fliserne som et eksempel på et relativt nyt forskningsområde, "spil til sundhed" (Games for Health), hvor digitale spil er redskaber til at opnå sundhedsfremmende aktiviteter hos brugere.

Afhandlingen starter med en præsentation af resultaterne fra to forskellige pilotforsøg udført med MOTO-fliserne, der begge viste en bemærkelsesværdig god udvikling hos de ældre brugere, især med hensyn til balance. Afhandlingen kontekstualiserer efterfølgende MOTO-fliserne i forhold til forskningsområdet "spil til sundhed" igennem en redegørelse for forskning udført på dette felt, herunder særligt "exergames", som betegnelsen for spil, som kræver, at brugeren skal være fysisk aktiv for at spille. Denne redegørelse påpeger, at forskningen hidtil er utilstrækkelig i forhold til den videnskabelige gyldighed. Gennemgangen af randomiserede kontrollerede forsøg (RCT) udført på området viser, at der er behov for flere undersøgelser og for studier af en højere metodologisk kvalitet.

Baseret på den viden, der blev opnået i pilotstudierne analysere og redegør

afhandlingen derefter for, hvordan RCT'er udføres, og hvordan man sikrer sådanne studier af høj metodisk kvalitet. Denne viden fra analysen anvendes til at planlægge og gennemføre et RCT på MOTO-fliserne med ældre mennesker i alderen fra 70 og op.

Resultaterne fra denne RCT viser, at det er muligt at gennemføre et studie af høj metodologisk kvalitet på feltet, men der peges også på problemer i testen, der til dels har at gøre med den pågældende aldersgruppe, herunder et problem med manglende data på grund af for eksempel pludselig sygdom, som er almindelig blandt ældre. Ikke desto mindre viser resultaterne af RCT'en et signifikant resultat (en stigning på 22 % i testen "Chair Stand"), og et andet resultat viser tegn på, at der kan være et vigtigt klinisk fund (et fald på 12 % i testen "Timed Up & Go"), mens et resultat er upåvirket (ingen forskel i testen "6 minutters gangtest"). Det konkluderes, at der er behov for flere undersøgelser, og at det bør overvejes at involvere flere deltagere i testene eller udføre meta-analyse af flere undersøgelser.

I forbindelse med RCT'en blev resultaterne fra de to pilottest desuden klart bekræftet, idet deltagerne fik statistisk signifikante forbedringer balancescore (testen "Linie Walk" eller "Tandem Walk") med en imponerende stigning på 149 %, hvis der justeres for en outlier.

Ud over de fysiske målinger har deltagerne også rapporteret fra testen via et spørgeskema og her viser resultaterne, at langt størstedelen af deltagerne fandt træningen underholdende og ønskede at fortsætte med træning på MOTO-fliser. Over halvdelen tilkendegav også, at de følte de havde fået det generelt bedre, og 75 % angav, at de havde forbedret sig fysisk. Dette viser, at playware såsom MOTO-fliser kan fremme sundhed og ikke mindst, at det kan gøres på en legende og dermed motiverende måde.

Med udgangspunkt i disse resultater, undersøger afhandlingen yderligere, hvordan MOTO-fliser som et eksempel på playware og exergames skaber leg blandt brugerne. Denne undersøgelse starter med en gennemgang af den filosofiske forståelse af begrebet leg, der er grundlaget for moderne spilforskning. Leg forstås her som noget, vi mennesker engagere os i, udelukkende på grund af den nydelse det bringer, eller som det er formuleret: Leg bærer sit formål i sig selv.

Ud fra denne forståelse redegør afhandlingen for, hvordan vi i leg har en særlig indstilling til verden. I leg er vi en særlig ”legestemning”, der rammesætter vores handlinger. Endvidere redegør afhandlingen for et vigtigt resultat i playware-forskning, nemlig at vi for at komme ind i legestemning bruger redskaber, såsom spil, legetøj, lege osv. Dette perspektiv bliver yderligere udviklet i afhandlingen ved at anvende Aktør Netværks Teori (ANT) som analyseramme, hvor ved der i afhandlingen udvikles en ny, orginal forståelse af spil som "aktører", der får spillerne til at handle på særlige foreskrevne måder med det formål at bringe dem i legestemning. Denne synsvinkel giver et nye perspektiv på spil og skaber en ny for undersøgelser af, hvordan legeredskaber virker på os som brugere.

På baggrund af dette nye perspektiv udvikler afhandlingen begrebet "legedynamik", der er defineret som dynamikker, som legeredskaber tager i anvendelse for at bringe spillere i legestemning. Eksempler på sådanne dynamik præsenteres, og afhandlingen peger på behovet for at videreudvikle vores forståelse af dynamikkerne, herunder forståelse af forskellige typer af dynamikker og af, hvordan dynamikkerne arbejder sammen om at skabe nye dynamikker og effekter.

List of Publications

The following papers are included in the thesis and are listed in chronological order.

(A) H. H. Lund and J. D. Jessen. “Effect of Playful Balancing Training-A Pilot Randomized Controlled Trial”. *2013 ISAROB*, 2013.

(B) H. H. Lund and J. D. Jessen. “Effects of short-term training of community-dwelling elderly with modular interactive tiles”. *GAMES FOR HEALTH: Research, Development, and Clinical Applications*, 2014.

(C) J. D. Jessen, H. H. Lund, and C. Jessen. “Physical computer games for motivating physical play among elderly”. *Gerontechnology*, 2014.

(D) J. D. Jessen and C. Jessen. “Games as Actors”. *International Journal on Advances in Intelligent Systems*, 2014.

(E) J. D. Jessen and H. H. Lund. “Playful home training for falls prevention”. *Advanced Intelligent Mechatronics (AIM), 2015 IEEE International Conference on*, 2015.

(F) J. D. Jessen and H. H. Lund. "Study protocol: Effect of Playful Training on Functional Abilities of Older Adults - A Randomized Controlled Trial", BMC Geriatrics, (submitted 2016)

Finally the thesis include the following unpublished contributions:

Chapter 4 "A Theory of Play Dynamics"

Chapter 7 "Effect of Playful Training on Functional Abilities of Older Adults - A Randomized Controlled Trial"

Acknowledgments

Getting to work with and write about play and playware is gratifying in itself. When this is then combined with the possibility to make a difference for people, it only becomes more of an honor. In this thesis, I have had the opportunity not only to dig into research about play and observe people's play, but also to participate in play and see how this affects others. The findings are based on the contributions of many people, from strangers I have met at exhibitions to research colleagues and participants in the studies I cannot include my thanks to all of them, but I would like to name a few.

Henrik Hautop Lund has supervised the PhD project, and I would like to thank him for all the help, discussions and talks we have had over the last years. My colleagues, David Johan Christensen and Moises Pacheco, for the many talks about play and playware. Per Kjær and the rest of the people from the Patient@Home project, who have supported the project and given me valuable insights in the area of quantitative studies, so new to both me and the Center for Playware. Carsten Jessen for co-writing some of the papers, and for always being ready to discuss play and playware with me.

I had an academic stay at University of Siena, and I would like to thank Patrizia Marti for allowing me to visit. I would also thank Iolanda Iacono and Michele Tittarealli for their warm welcome and help for me and my family when we stayed in Siena. Further, I would like to thank them all for the many interesting talks we shared during my stay.

Writing a thesis has been hard works at times, and for this I would like to thank my family for their support and understanding; you have been there to help me whenever I needed it. Thank you.

I dedicate this work to my wife, Rinie, and my children, Aviaya, Smilla, and Malia, who always inspire me and comtinue to do so. I would like to tell them what a play researcher once told me: The true meaning of life is play, for in play we are truly free, happy, and living up to our best of our abilities.

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Chapter 1

Introduction

In this PhD thesis I will present the work I have done over the last three years working with play as well as an example of what has been termed playware technology, the MOTO tiles (www.moto-tiles.com). The thesis is highly cross-disciplinary and has several different but highly interrelated areas of research; Play and Playware, Technology and Quantitative Studies (including Randomized Controlled Studies). Because playware is a new research area, which only few readers can be expected to know, the following section contains a brief introduction to the concept and its history.

1.1 Playware

The main research area of this PhD thesis is playware. In the following we will look at what playware is, and how this research field was formed.

Playware is a relatively new research area formed in the early 2000s by Henrik Hautop Lund, robotics professor, and Carsten Jessen, play researcher. In 2005 they coined the concept of playware and defined it as:

> ”intelligent hardware and software that creates play and playful experiences for users of all ages.” [6].

The field of playware emerged partly along with the growing trend of children and young people using electronics and digital media in play. This growing trend was coupled with an increase in obesity among children and young people. The increase of obesity was a major concern, and some researchers blamed electronics and digital media [7, 8]. Furthermore, these researchers claimed that electronics and digital media would seriously harm children's abilities to engage in social and fantasy play [9, 10].

Lund and Jessen had another starting point for their research. While they agreed that electronics and digital media could partially explain the problems, they belived it could also serve as part of the solution [11]. Furthermore, Lund and Jessen pointed out that children's play culture had changed dramatically, and while earlier generations frequently had contact with older children [12, 13], this was not the case for the current generations [14]. Previously play was passed on from generation to generation because of frequent interaction across age groups. The older children were "masters-of-play" and could teach the younger children the rules and tricks of different forms of play and games [11, 13].

The lack of contact between young and old children created a growing need for new products, which could inspire play the same way the masters-of-play used to [11]. According to Lund and Jessen, this need was also part of the reason why computer games had become so successful. Computer games materialized the rules used to inspire play into the software [11]. Thus, computer games can be regarded as tools to initiate play activities in social settings.

Lund and Jessen pointed out that the goal for research and development in the field of playware should be to take advantage of the motivational elements that we can find in computer games, and then to use them to create new kinds of play environments and types of play equipment which encourage engagement in physical activities [11].

Therefore part of the goal in playware research is to understand how games, toys and other types of playware equipment work, and what it is that motivates us to engage with them.

While the change in play culture and the success of computer games and digital media constituted half of the framework for the development of the playware research area, robotics and what has been termed "modern" Artificial Intelligence (AI) constituted the other half.

Research in robotics and AI had long been focused on separating the "body" (hardware) and the "brain" (software). Part of this changed during the 1980s and 1990s, when researchers began to propose a different approach to the field [15]. Lund and colleagues did research into how certain behaviors could be reached by changing the parameters of the body and how this in turn changed the brain structure needed to preform the same operations. They showed how this relationship between the body and the brain worked by re-creating cricket behavior through the design of a robot cricket. Here, they were able to show that changing the body model meant that they could design a more simple brain model to get the same behavior as observed in the natural setting [15, 16].

Research into how the design of the body impacted the needed brain structure made it clear that the study of AI could benefit from an understanding of intelligence as embedded in the body, and an understanding based on the idea that we cannot effectively abstract the body away, when we create robots and intelligent systems with behaviors [15].

At the same time, technological development made it possible to create ambient [11] or pervasive technology [17], which made it possible to include technology in just about any object anywhere.

With the background in play, play culture, modern AI, robotics and ambient technology, the research field of playware emerged. This field has inspired and produced several different projects all forged around the ABCs of playware which Lund formulated as: developing technology for Anybody, Anywhere, Anytime by Building Bodies and Brains, which allows end-users to Construct, Combine and Create [15, 18].

As presented above, the research field of playware insolves investigation into the use of technology to inspire and create what we normally label 'play'. Computer games are the most known and successful example of playware, but the term playware goes far beyond computer games, and includes intelligent play tools that use modern day technology to create experiences of play and playfulness. Lund and Jessen created the Center for Playware in 2009 at the Technical University of Denmark, where research on play, modularity, interaction, robotics and embodied AI is combined in order to create new and innovative products. The examples of the applications of products created as a result of the research into and development of playware are numerous and include areas such as rehabilitation, exercise, play, creativity, art, learning, and innovation (see also figure 1.1).

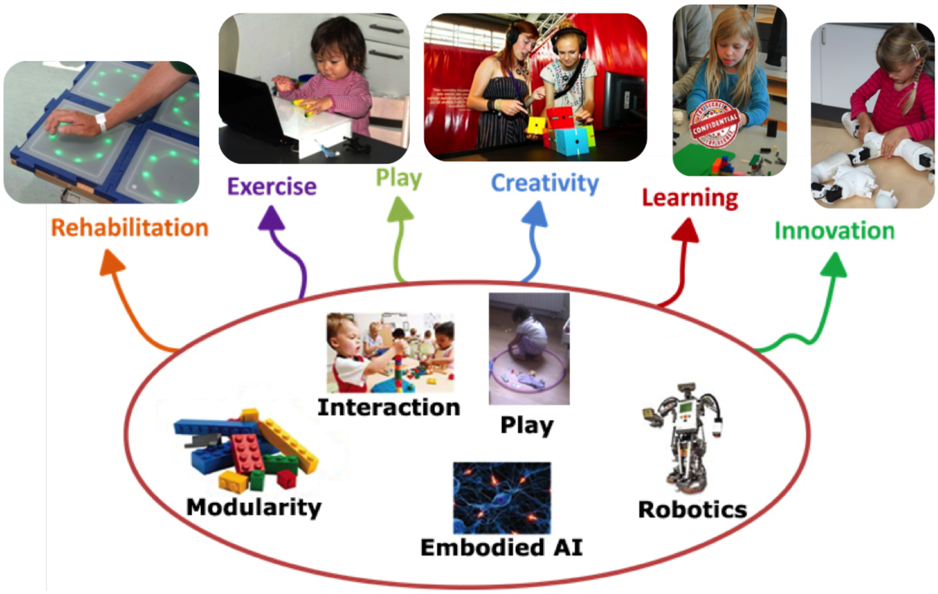

Figure 1.1: The research areas of playware and some of the application areas.

All of the applications of playware technology have user interaction as the center of their objectives, in the form of creating play through the free, voluntary activity of engaging with the technology. While play is at the center of the interaction, collateral effects (e.g. in the form of learning or physical improvements) are both designed for, and carefully developed into, the products [19].

Examples of the uses of playware technology are RoboMusic cubes [20, 21], Fable[22], and MOTO tiles [2].

RoboMusic cubes are cubes allowing the user to make or perform music in a simple and intuitive manner. The cubes build on technology created at the Center for Playware called I-BLOCKS [23], which were used to create a prototype allowing anyone to remix music [20, 21]. This system consisted of cubes (I-BLOCKS) that could be easily attached to each other. The system was able to detect which blocks were attached and which side was facing up. Using this information, the researchers created a system where each cube represented an instrument: e.g. one was a guitar, another vocals and so on. When the user turned the cube, another musical variation on the same instrument, from the same song or genre, was played. If a cube was detached, it would stop that instrument from being played and start playing any instrument that was attached at any point. This project showed that using playful interactions with music in this way allowed even small children to get the feeling of creating their own music and being part of it [20].The cubes have been used at multiple sites and with great success.

The cubes were also part of "the first robomusic concert" [24, 25]. In this concert, the participants could engage in the music by interacting with playware objects such as the cubes, "rolling-pins" they could roll, and tiles they could step on in order to change the musical expression.

Later, the cubes were developed further into both small (4x2x2cm) and very large (1x1x1m) cubes, along with a software version, where the manipulation is done solely on an iPad (http://www.musictiles.com/) [26].

The "rolling-pins" that were used in the concert were tubes 300mm long and 50mm in diameter. They were semi-transparent and able to light up in different colors as well as produce sounds and vibrate [27, 28]. They were among other things used to create tailored stimulation in the treatment of people with dementia.

Another project, Fable, has emerged from some of the many research projects Center for Playware has done with LEGO. Fable is a modular robotics system that consists of a variety of different modules that are easily assembled in a matter of minutes. The modules are able to communicate with computers or tablets, allowing users to easily program the robot they build. Fable is a modular robotics system that allows non-expert users to develop and play with robots ranging from advanced toys to robotics solutions for use in daily lives. The system was developed for pupils, students and researchers [22].

Playware was also used to create the first digital playground [29]. In this playground the children could run around and play games by pushing buttons and competing against each other among other things. From this project emerged what would later be termed the MOTO tiles.

MOTO tiles [18, 19] are a distributed system of digital tiles able to sense pressure (e.g. from stepping on them). They then light up in a rainbow spectrum of colors from eight RGB light-emitting diodes (LEDs). The LEDs are placed in a circle with equal space between them (see also figure 1.2). Each tile works independently, but is controlled using a tablet. They are 30cm x 30cm and shaped as puzzle pieces, making them easy to setup in the desired formation. This formation then makes up the playing field for the players.

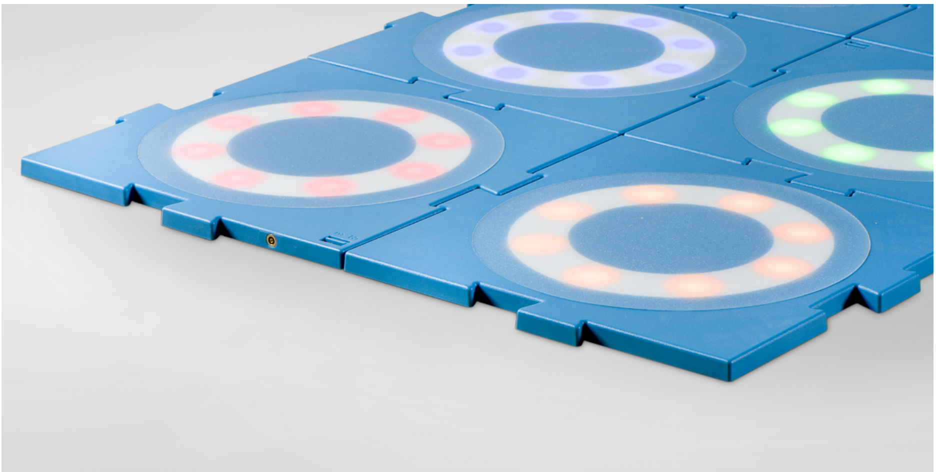

Figure 1.2: The MOTO tiles.

The many colors allow for a variety of different types of patterns and games. To play a game on the tile platform, a player must move around and step on the tiles according to the rules of each game (e.g. step on all the tiles that light up in red). The various games can either be played by a single person or by multiple people collaborating with, or competing against, each other.

The tiles are designed to work in any combination and setup, giving the user the ability to create almost any playing field they want, and to change it again at any point - e.g. change the size (number of tiles) or shape (how they are put together) of the field of tiles. When the user changes the configuration of the tiles, this changes the interaction with the tiles and the difficulty, e.g. faster/slower movements, longer/shorter steps etc. As such the user has the ability to physically build different platforms and thus change the movement and difficulty of the games.

The tiles have been used as balance training for older adults (65+ years old) and motor skills training for children (5-6 years old) among others [2].

Regardless of the application area of the individual products, the essential point is that playware has a potential to both utilize play and collect the collateral effects of the playful engagement if the products are designed the right way. This thesis will not only demonstrate that the MOTO tiles can have a remarkable effect on the health of elderly people, but also try to explain why this is the case, which demands a rather comprehensive evaluation of the concepts of play and games. For playware technology to be successful, it is important to understand both how we create playful experiences, and also how to evaluate whether or not the technology used is suitable, and produces the desired effects. The main contributions to the research field of playware from this thesis will be within these parameters.

1.2 Main contributions

The thesis is an investigation into a new technological product, which uses play to motivate the elderly to undertake physical training that can improve their physical health. The product, MOTO tiles, is an example of “playware”, but also of the broader field of research, Games for Health, which is a relatively new but growing area. The ambition of the thesis is to contribute to the development of the research area by conducting a Randomized Control Trial (RCT) to a methodological standard, so that it can produce a credible scientific validation of the effect of a Games for Health product. In continuation hereof the ambition is to establish a foundation for the understanding of how games function as vehicles for creating playful experiences, which can motivate users to act in certain ways that are relevant to the desired outcome.

The contributions are presented in five peer reviewed papers, which are part of the thesis, and in the chapters following them, where the RCT is presented for the first time. In summary, the contributions are listed below, starting with the peer reviewed papers:

- Paper B "Effects of Short-Term Training of Community-Dwelling Elderly with Modular Interactive Tiles": This paper presents the first results of a pilot study of the effects of playful balance training with elderly people on the MOTO tiles. The paper reports the findings of the use of playware technology regarding the enhanced mobility, agility, balancing, and general fitness of community-dwelling older adults, and explores how this was accomplished in a playful manner. The study also outlines how it is possible to use this kind of technology in practice at centers for older adults.

- Paper A "Effect of Playful Balancing Training - A Pilot Randomized Controlled Trial": This paper presents the pilot RCT using the MOTO tiles for playful balance training. The paper contributes to the existing research on how a Randomized Controlled Trial can be planned and conducted in practice with playware technology, and how investigations into the effects of the training can be done.

- Paper C "Physical computer games for motivating physical play among elderly": This paper deals with the physicality of the MOTO tiles and presents new knowledge about how the physical setup is motivating for the participants. One important finding was that games involving both physical and mental challenges were particularly motivating for the elderly.

- Paper D "Games as Actors - Interaction, Play, Design, and Actor Network Theory": The ambition of this paper is to develop a new theoretical perspective on how games can been understood as actors that have the capability to push the users into doing certain activities, for instance physical motion. Using as a basis the social theory developed primarily by Bruno Latour, the Actor Network Theory, the paper establishes an original framework for analyzing games, which shows how we can understand what games do to the bodies and minds of users, and how this understanding can help in the design of playful technology such as computer games and playware.

- Paper E "Playful Home Training for Falls Prevention - A pilot study using a mechatronical exergame": This paper is a presentation of studies done with the elderly in private homes with the MOTO tiles for playful exercise. The findings were that playful home training on the MOTO tiles can motivate participants to train 1-2 times a day and that the training continues to be both fun and motivating after training up to 70 times. Further, the paper presents a framework for future research on playful home training.

The thesis further includes the unpublished work as follows:

- Chapter 4 "A Theory of Play Dynamics": The chapter presents one of the essential contributions of the thesis with regards to the theory of play and games as motivational causes in playware products and exergames namely, the work of developing the theory of play dynamics. Here the notion of play as a state of being in the world is presented, and the notion of how “play tools” (toys, computer games etc.) work by taking advantage of play dynamics. A preliminary framework for analyzing which kind of play dynamics are utilized by play tools is developed, with the goal of delivering a foundation helping designers to better understand and take advantage of these dynamics.

- Chapter 7 "Results of the Intervention - the Effect of Playful Training on the Functional Abilities of Older Adults - A Randomized Controlled Trial": This chapter presents the findings of the RCT conducted as part of this thesis. It demonstrates that it is possible and suitable to do a study of high methodological quality on playware and exergames, which involves the blinding of the assessor, the randomization of the participants, concealment of the allocation and reports on all outcomes.

The findings of the study show positive outcomes that are significant, i.e. the aforementioned increase of 22% in the test “Chair Stand”, and a decrease of 12% in the test “Timed Up & Go”. Besides that, the study connected to the RCT revealed an increase of 149% in the test regarding balance. The author concludes that more studies are still needed and that higher power of the studies should be considered or meta-analysis on several trials should be combined.

The chapter also serves as an example of how to report findings based on the guidelines of best practice within the field of RCTs.

- Paper F "Study protocol: Effect of Playful Training on Functional Abilities of Older Adults - A Randomized Controlled Trial": This paper, which is unpublished but currently under review, presents the protocol for the conducted RCT. Such a protocol is a prerequisite of RCTs and vital for the validity of the results.

- Appendix G "Complete study protocol: Effect of Playful Training on Functional Abilities of Older Adults - A Randomized Controlled Trial": This is the complete protocol developed for the RCT study done as part of this thesis. This presents all the considerations and choices taken leading up to the intervention.

- Appendix H "MAST analysis of MOTO tiles": This is a Danish analysis of the

MOTO tiles based on the "model for asessment of telemedicine applications", or MAST.

1.3 Background

MOTO tiles are the subject of research in this thesis. The tiles are currently used in balance training for elderly people, and day-centers for older adults, physiotherapists and other professionals in this area are doing pilot projects with the MOTO tiles. Some of these projects will be presented later, but two early studies were an important point of departure and constitute part of the thesis. The early studies will be presented in the following section, which also serves as an introduction to the main issues in the thesis.

1.3.1 The pilot study

In 2012 the Center for Playware, including the author of this thesis, conducted a research project called “LevVel” (“live-well”) which aimed at investigating if balance training with a prototype of the MOTO tiles would increase the balance of community-dwelling elderly people. The findings of this project are also described in the paper “Effects of Short-Term Training of Community-Dwelling Elderly with Modular Interactive Tiles” (paper B), but the findings will be briefly presented here.

In the first pilot study 18 community-dwelling elderly individuals participated in playful training on the MOTO tiles once a week over a 12-week period. The author of this thesis supervised and organized the training sessions, which was done in groups and lasted for 1-1.5 hours with each participant being active for 10-15 minutes. The training was structured so that each participant played for 1.5-2 minutes and then rested for 6-8 minutes, while the rest of the group trained (see example in figure 1.3).

The project was, as mentioned, a pilot investigation of the use of playful training on the MOTO tiles for elderly people, which had not been investigated before.

The participants were tested before and after the intervention with assessments from the Senior Fitness Test [30]. These processes will be described further in

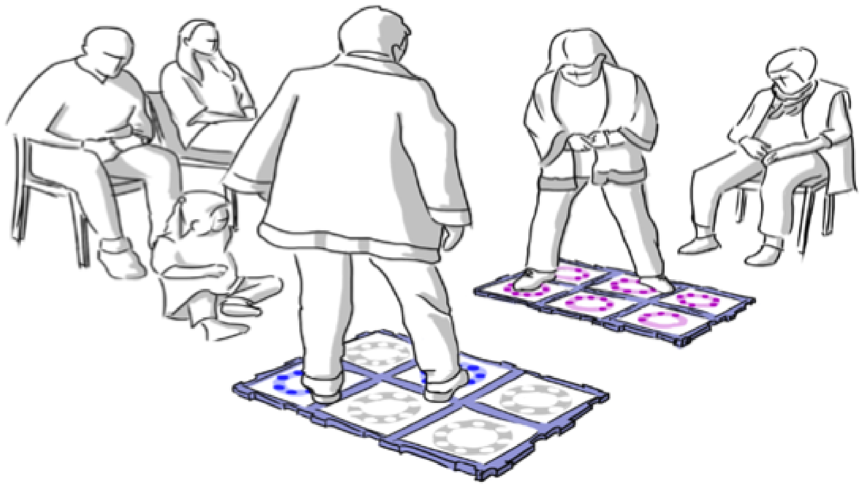

Figure 1.3: The MOTO tiles.

chapter 7, as the test is used in later projects as well. Briefly described, the Senior Fitness Test measures the "...underlying physical parameters associated with functional ability, and identifies whether an older adult may be at risk for loss of functional ability." [31].

During the training sessions we discovered how valuable the play element of training with the MOTO tiles was. While we expected that play would help make the training more fun, we could not have predicted how great the improvements for the participants would be.

The results of the pre- and post-tests showed a statistically significant increase in the underlying physical parameters ($p<0.002$ and improvements of 14-22.4%) after training 10 times and with 10-15 min of active training each time [2].

These results made it clear that playful training on the MOTO tiles gives a statically significant improvement and could lead to better balance.

The pilot project with the MOTO tiles also investigated how play could motivate the players. During the sessions observations were made, and after the intervention interviews were conducted, partly by the author of this thesis, and partly by representatives from our collaborator, Gentofte municipality. These data showed that physical play on the MOTO tiles was highly motivating (see paper B and C, and Danish report: [32]).

After the project described above, another was conducted and planned with Lyngby-Taarbæk municipality. This was a pilot study with a control group, but only 12 participants in total. In this study, another test called Dynamic Gait Index (DGI) [33, 34] was used (for details on this test and the intervention, see paper A).

The results of the second test showed that the intervention group had an increase in performance of 12.3% and this was significant ($p<0.05$), while the control group had a 9.3% decrease in their performance, but the result was statistically insignificant [1].

The DGI test has the problem of what is called a "ceiling effect" [35], which some of the participants ended up hitting. The ceiling effect is a matter of the test having a maximum score (here, 24), and any improvement beyond that will not be reflected in the score. In this case, a few of the participants hit the maximum score, and thus the improvements could have been even more significant, but the test was unable to detect this.

While the two projects each showed that training on the MOTO tiles could be beneficial, a review of the research done in the area pointed out that there was still insufficient evidence to conclude that games used to improve health, such as the MOTO tiles, were effective for older adults [35] (this point will be elaborated on in chapter 2). Therefore, this pointed to the need for more research in this area. This thesis is one of the many contributions to this evolving area of research.

1.3.2 Hypothesis and investigation

MOTO tiles as presented above, are an example of technology gaining an increasing amount of interest as the numbers of older adults in western societies grows. This, along with the findings from the pilot study, made the foundation for the topic of this thesis, which is "Evaluation and understanding of playware technology". This title points to two different parts of the thesis, "evaluation" and "understanding", and these are the two areas which this thesis tries to combine into one whole. In order to structure the work and the findings, we will look at the two different parts and what kind of investigation and research they contribute.

The focus point for an evaluation of playware technology is on any evidence of the effect of the products. The question is if we can gather evidence that the technology can have an effect that we value (e.g. contributing to better balance). While evidence can be found in many ways, the main method of evaluating evidence in this thesis will be by doing a "Randomized Controlled Trial" (RCT) of the MOTO tiles. An RCT was chosen because it is considered to be the gold standard for identifying the causal relationship between an intervention and the outcomes [36].

This leads us to the first hypothesis of this thesis:

> Hypothesis 1:
>
> *Playful training on the playware tiles (MOTO) will give statistically significant increases in the underlying physical parameters when compared to usual care.*

With regard to "understanding" we are putting emphasis on the second part of the study done in this thesis, which goes into how the MOTO tiles motivate users to exercise, and what exactly it is that brings about the effect we are investigating, which the pilot studies also indicate.

These questions are put together in the second hypothesis:

> Hypothesis 2:
>
> *Playware affects the participants by bringing them into play, and thereby motivating them to do to what they would otherwise not do.*

The two hypotheses will be investigated in different ways, but the outcome of the investigations will lead to the main conclusions of this thesis. As presented, the first hypothesis will mainly be investigated through an RCT, but the foundation for it is based on the pilot studies of the MOTO tiles.

The second hypothesis will be investigated by studying if, and how, the MOTO tiles create play. This investigation will be based on studies in contemporary play and games theories, with a particular focus on how games and play work for, and in, humans, and how play motivates us.

In general, the research presented in this thesis builds on two pillars. First, the quantitative research on the effects of a playware product (the MOTO tiles) that potentially can improve health, as is investigated in the first hypothesis. The second part is the understanding of play as explored, partly by the second hypothesis.

These two pillars support each other, as there is need to prove that the play the MOTO tiles create actually work (i.e. leads to a physical outcome), but there is also need to understand how the MOTO tiles and similar technologie can create play of this type, that can have the desired effect on health.

1.4 Thesis outline

The thesis is written as a collection of publications (A, B, C, D, E, and F) and additional material (G and H). The main text contains introductions to the area of research related to the publications, along with some of the latest unpublished results (chapter 4 and 7). The thesis starts in chapter 2 with an introduction to the area of games that aims at improving health. Chapter 2 also presents the sub-area called “exergames”, focusing on research done on the elderly and balance. The understanding of play is presented in chapter 3, and further developed in chapter 4 where a theory of play dynamics is presented. Chapter 4 is constructed as a paper to be published.

In chapter 5, the thesis sums up the research done on play and points to chapter 6, where the history and current guidelines of RCTs are presented. Based on the guidelines presented in chapter 6, an RCT with the MOTO tiles was conducted and the findings are presented in chapter 7. Chapter 7 is also structured as a paper to be published.

Finally, the implications of the research are discussed in chapter 8, and conclusions and future work are presented in chapter 9.

Chapter 2

Games for Health and Exergames

MOTO tiles [2] are one type of playware focused on rehabilitation and exercise. The tiles are also an example of a product from an area of research which has grown in recent years, called ”Games for Health” [37]. In the following, we will look at these types of games, both with a historical review and a state-of-the-art of the sub-area of games for health that is one of the main subjects in this thesis – called “exergames”. Exergames aim to activate users physically; the MOTO tiles is an example of an exergame.

Investigations into games for health is a broad area representing research that utilizes games for the purpose of improving health. Bill Ferguson, editor of Games for Health Journal, formulates it this way: "...the Journal will strive to publish research articles concerning games that improve ’physical, mental, or social well-being’ via proactive or remedial activities." [37].

Games for health focuses on how healthcare services have undergone significant changes in recent years. Technologie used in healthcare services are rapidly changing the doctor-patient relationship, from patients searching their symptoms online to the advent of technology that is able to track people’s health and in general help them to manage their health in almost every aspect of life [37].

In the following, we will take a deeper look into the research conducted on games for health. The next sections will serve as an introduction, which should demonstrate how broad the research field is. After that the focus will narrow down to exergames.

Pamela M. Kato [38] presented a comprehensive review of the early research done with games for health including descriptions of the application areas. Further, Hadi Kharrazi and colleagues [39] did a scoping review of the area of health game research. The sub-chapter is partly based on those comprehensive reviews of the area as well as other studies [36, 40, 41, 42].

2.1 History and early application areas of games for health

According to Kato and Kharrazi, the first studies of digital games as tools for health improvement date back as early as the 1980s [38, 39], but the first twenty years of games for health research is a period before research in the field reached “critical mass” [36]. As such, it mainly involved pilot trials and investigations into how games could be used in health-related areas.

Games for health have been studied in different settings, including games as a kind of distraction from unpleasant treatment, as motivation, as tools for learning, and games for cognitive or physical training. In the following we will look at a broad segment of the early research done in the area.

In two studies from the 1980s [43, 44], researchers investigated the effect of play during chemotherapy for children. The study found that playing videogames showed a significant decrease in the reported nausea compared to a control group. The control group were allowed to play with non-digital toys, games, books and watch TV. A later study [45] showed comparable significant effects compared to a control group, though the effect was similar to supervised relaxation training [45].

A video game designed to improve self-care among children and adolescents with diabetes was studied in an RCT. The intervention group played the game for six months [46]. Not only did the study find that the intervention group showed increased self-efficacy and self-management, but they also had a 77% decrease in unscheduled diabetes-related doctor visits [40, 46], which clearly demonstrated learning.

Education of both a preventive and self-management/efficacy nature has also been a focus for other investigations in the early research. Studies of children with asthma playing educational games indicated that an asthma-specific computer game can significantly affect knowledge, behavior and management. Further, the studies showed fewer hospitalizations and, better symptoms score, indicating that the interventions may potentially affect morbidity in childhood asthma [47, 48].

The effect of video games training on bodily functions has been demonstrated on dysfunction in the bladder and bowel [49, 50]. Here biofeedback was used to train the patients to better control their bladder function, by letting them control games using sensors that detected muscle activity. The results showed improvements in both self-reported measures and objective measures [49, 50]. In a similar fashion, using biofeedback to control a game for patients with irritable bowel syndrome found that more than half the patients showed significant reductions in symptoms, also in a long-term follow-up [51].

In the area of preventive interventions, the topics of education in adolescent pregnancy prevention [52, 53], AIDS [54], smoking prevention [55, 56] and drugs [57] have all been investigated and the results of these studies indicated that the games could have an effect on the target groups.

Passig and Eden did interventions with deaf and hard of hearing children involving virtual reality technology games. The results indicated that these children improved significantly in their understanding of induction skills [58], flexible thinking [59] and spatial rotation [60], all areas where the deaf and hard of hearing children had previously lacked abilities [61].

One of the most relevant areas in regards to the subject of this thesis is, of course, physical therapy and fitness. Studies in the 1980s and 1990s took advantage of the physical requirements for playing video games (e.g. manipulation of a joystick) and investigated if they could improve physical therapy after arm injury [62]. Later, traumatic brain injury [63] and children with Erb's palsy [64] were investigated. The studies indicated successful results, and the results could at least partly be explained as a solution to a major problem in rehabilitation, increasing motivation and engagement in otherwise repetitive tasks [38].

As can be seen by the above review of the historical research, games can positively affect health, but the review also shows that the area it covers is broad. According to Kharrazi et al. [39], more than 70% of the publications up until 2012 were written after 2005 thus, the review above is only a small subset of the complete literature and research in the area. Giving a complete overview of the research in games for health from 2005 and onwards is outside of the scope for this thesis. In the following, we will look at the main subject under the games for health area that we will be working with. This will narrow the focus on games for health to games for physical training, while the other areas are left behind. In an attempt to clarify and contextualize our perspective on games for health, the next section will also include an introduction to the issue the MOTO tiles aim to address, i.e. improving the health of the elderly.

2.2 Health and balance

The notion of "health" is often connected to illness, but in games for health the notion is derived from the official definition developed by WHO: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." [65]. The point is that health is as much an issue of well-being as it is the absence of illness.

One area of increasing focus in health is the demographic development in the west and other countries, where the amount of adults over 65 is growing. With increased age comes many different challenges for the individual and society, and one of these is the decrease in body balance and, associated with that, falls. While lack of balance is not necessarily a disease, it certainly involves a lack of physical and, to some extent mental well-being. Balance is also one of the main objects of study that will we work with in this thesis, not least because balance is a huge problem among the elderly.

2.2.1 Balance

The current research on balance among older adults shows that approximately 30% of community-dwelling adults aged over 65 years fall every year [66]. The most common reason for older adults falling is the loss of functional abilities as a consequence of a sedentary daily lifestyle, and it is well established that physical activity can effectively reduce this loss of capabilities [35, 67]. One third of senior citizens aged 65-80 fall at least once a year [66], and half of those over 80 [68, 69, 70]. Of these, 40-60% result in injury. Most are minor injuries (30-50%), but about 5-6% result in fractures and up to 1% are hip fractures [71]. In Denmark, around 13,000 hospitalizations per year were associated with falls in 2005, and this is expected to rise to around 24,000 per year in 2030 [72].

The reasons for older adults having a sedentary lifestyle have been investigated in several studies, and the main barriers for training and exercising include internal barriers such as tiredness, a lack of motivation and poor health, while the external barriers include the lack of companions, opportunities and time [73, 74].

Falling and interventions to reduce falls is a research area of growing interest, both because of the magnitude of problems associated with falls and because of the economic expenses in healthcare due to fall-related accidents.

A Cochrane review has been done in the area of older people, balance and falls. The review titled “Interventions for preventing falls in older people living in the community (Review)” [66], found that 159 RCTs have been reported with interventions aimed at preventing falls among adults 60+. The 159 trials had a total of 79,193 participants, and 59 of these trials (13,264 randomized participants) tested the effect of exercise on falls [66].

While prevention of falling is a well-researched area with indications that exercise can significantly reduce the rate of falls and risk of falling, the outcome of single category programs (e.g. retraining or muscle strengthening alone) lack evidence [66].

In the above mentioned interventions the form of exercise used is traditional “gymnastics”, and games have until recently only been used in small pilot studies as presented above. The emergence of new digital technology has resulted in the deveolopment of products which are well-suited for physical training, giving cause to a new and emerging area that we will look into in the next section.

2.3 Exergames

From 2009, a sub-area within games for health emerged with a focus on what have been called active video games, exertion games, exertainment, active-play videogames, interactive computer games, game-based technology-mediated physical activity or exergames [35, 75]. Here we will use the notation exergames to cover any of the notations above.

Exergames are games where the players interact with the computer by using input devices that require the users to be physically active when they play. These games incorporate and combine play, technology, and physical activities, and in exergames the player uses his/her body to play the game. The games use different input technologies to track the player's movements or reactions. The overall goals of exergames are to overcome some of the barriers for training and exercising as mentioned earlier.

Exergames has a relatively long history, and the first commercial products reached the markets as early as 1982, when Atari marketed "Joyboard" a simple balance board, which players stood onto control the movements of a figure in a computer game. In the years since that different companies marketed products which required physical activity by the player. Examples are bicycles connected to video games, or the Dance Dance Revolution (DDR) from 1998, where the players had to step on a platform that resembles a control pad [76].

DDR had some penetration in video arcades, but exergames were not a commercial success in homes before Nintendo marketed the well-known Wii in 2006 with games like Wii Fit which works much like the Atari Joyboard, alongside Wii Just Dance. Other products are Microsoft's Kinect from 2010, which introduced a new technology that uses an infrared camera to track player movements [35, 75].

While exergames are being tested for many different types of health improvements [77, 78], here the focus is on balance training for older adults. The field of exergames used for balance improvement for older adults is growing, but recent reviews and meta-analysis show only a very limited amount of randomized controlled trials have been carried out [35, 77, 78, 79, 80].

Larsen et al. [35] conducted the first review of the area and found that seven studies had been conducted. While the review indicated the overall positive effect of exergames (6 out of 7 had a positive effect), there was still a lack of evidence on the use of the games as an effective intervention for older adults as a means to prevent falls. In the review the authors also concluded that the diversity of the intervention, outcome measures, and durations of the interventions made it difficult to make any conclusions on the use of exergames for balance training. Three of the interventions combined exergaming with traditional exercise [81, 82, 83], making it difficult to distinguish between the positive effects from exergames and from traditional exercise [35]. Also, the duration of the interventions varied from three to 20 weeks, and the outcome measures used varied between the Berg Balance Scale (BBS) [84, 85], the Tinetti Performance-oriented Mobility Assessment (POMA) [86] or Timed Up and Go (TUG) [87].

Both the BBS and the POMA are characterized by having a ceiling effect, meaning that the score cannot get higher, even though the test subject improves. Larsen et al. [35] pointed to this, and stressed that it is crucial to select outcome measures that can detect improvements more accurately.

2.3.1 Recent research in exergames

While Larsen et al. [35] presented the initial systematic review of the area of exergaming for community-dwelling elderly people, more studies have been published since, as have newer reviews [77, 78, 79, 80]. In the following we will look at the state-of-the-art trials done in the field of exergames for the community-dwelling elderly.

The latest systematic review found 18 studies in the field [80]. A search for additional relevant studies in previous reviews, and studies published after this review date (April 2015) up to May 2016, revealed five additional publications [88, 89, 90, 91, 92].

Of the 23 studies identified, ten compared exergames with no intervention or usual care, nine compared exergames with conventional training, and four compared exergames with both conventional training and no intervention.

The most used exergaming system was the Wii system, which 13 trials investigated. Four used the Kinect and three used custom developed systems, while the last three used DDR or variations of this.

The durations of the interventions lasted from three to 20 weeks, with 6-8 weeks the most common, and typical contact with subjects in the study conducted 2-3 times a week [80].

The outcome measures of physical performance were mainly TUG and Chair Stand (CS), while the main indirect measures of balance were BBS and POMA [80].

Taylor et al. [80] concluded in their review that exergames are effective in improving the balance score on the BBS and the mobility on the CS. They further stated that some trials pointed out the problems of hitting the ceiling effect of the

BBS, as did Larsen et al. [35]. Both reviews pointed to the very low number of publications in the area [35, 80].

The reviews assessed the methodological quality of the studies by looking at the risk of bias in the areas of selection, performance, detection attrition, reporting and other biases. The assessments showed that most studies had a low to moderate quality (moderate to high risk of bias) [35, 80].

The low to moderate methodological quality of the studies points towards a need for higher quality studies, which Larsen et al. [35] also pointed to in their review. Before we venture into how to conduct higher quality RCT studies, which is another of the main topics of this thesis, we will take a look at how games for health motivate the participants, or, rather: how games make us do things we otherwise would not do [4].

Chapter 3

Play and Games as Actors

3.1 What is play?

In the following we will look at some of the classic play rhetoricians, who have contributed profoundly to shaping the understanding of play that is now dominant in contemporary play and game research [93, 94] and which this thesis builds upon, as does the concept and research on play and playware, primarily in research done by Jessen & Lund [11]. In this thesis, my ambition is to take this research a step further, which is the reason why the following goes to the basis of play theory instead of just giving an account of playware theory. We will look at the thoughts on the phenomenon of "play" from some of the most influential play scholars. Let us be clear, there are many different understandings of play in different areas of research and science. The intent of this chapter is not to give a complete overview of these, but to present the main contributions that constitute the foundation for the understanding of play that is fundamental to both this thesis and to playware research in general. We will look at how play is structured and what the different characteristics of play are, in order to establish a frame of understanding that is usable in the design of playware, especially in the light of playware as a motivator for physical exercise among users.

Because play is a concept with many definitions, it is not only important to account for how play is understood and used in this thesis, but also to mention wellknown definitions that are outside the scope of the thesis. It should also be mentioned in advance that the concept of play used in later chapters as a foundation for the understanding of the effect of play on people builds on a definition that, until lately (i.e. until video and computer games research developed), was at the edge of play research, which mostly focused on children's play. This is the reason for the rather comprehensive account in the following, where we will work towards a definition that can include any age and explain how play products function.

3.1.1 Rhetorics of play

A central figure in play research today is Brian Sutton-Smith, who for a lifetime has researched children's play. In his book "The ambiguity of Play" [95] he emphasizes that play research is characterized by a very large ambiguity in the interpretation of the concept of play. Although we all have a sense of what play is and often are able to point out when we or others are playing, there is still considerable disagreement about how we should understand the concept of play.

Sutton-Smith presents seven discourses of play, or, as he calls them, rhetorics that characterize research in and the understanding of play. Sutton-Smith emphasizes that they are just rhetorics, and therefore persuasion is a key point. The scientific work around play is characterized by researchers who use one of the seven rhetorics to convince others that the rhetoric they use is the right way to understand play [95]. It should be mentioned that this thesis is no exception, and as such, this thesis will represent one of these rhetorics about play but we will return to this later. First, we will look at Sutton-Smith's seven rhetorics.

Sutton-Smith divides them into the new and the traditional rhetorics. While the new rhetorics date a few centuries back, the old can, in some cases, be traced back to the ancient Greeks [95].

Among the new rhetorics we find the one that is probably the most prevalent in modern western societies; the discourse of play as development, which is the understanding of play one will find in developmental psychology and educational science, where play is regarded as something that develops children. According to this understanding, play is educative and the significance and meaning of play is justified in the learning that it produces. In this rhetoric, play is considered an important element in the development from child to adult, and play is portrayed as a means, targeted at development, rather than as a goal with enjoyment as the objective [95]. We will return to that later.

Play as being in the realm of the imaginary also belongs to the newer rhetorics. Here, play is considered to promote imagination and creativity. The rhetoric is evident in society's positive focus on innovation and creativity. Sutton-Smith points out that it idealizes the imagination, flexibility, and creativity of humans' (and animals') play worlds [95].

The last of the modern rhetorics is the rhetoric of self [95]. This rhetoric deals with hobbies and similar activities that focus on an experience that the player is seeking, and the intrinsic or aesthetic satisfaction it brings [95].

Among the traditional rhetorics we find play as power. This rhetoric is often used in sports and other competitions, and covers play as a representation of conflict and struggle, including the creation of heroes through play, such as sports stars [95].

Play as identity is another of the traditional rhetorics. This rhetoric is based on an understanding that groups maintain their identity, among other things, through rituals of a playful nature, such as celebrations and parties [95].

Play as fate, often used around games where luck is crucial, is yet another of the traditional rhetorics. Sutton-Smith emphasizes that this is probably the oldest rhetoric, which is based on the perception of human life as guided by fate, the gods, or luck [95].

Both the rhetoric of play as fate and the rhetoric of play as development stand in particular contrast to the last rhetoric; play as frivolity or as something "silly". This rhetoric can spur normative statements like "play is a waste of time", because play in this rhetoric seems senseless and silly, since play has no extrinsic outcome. But this rhetoric can also be understood as play having a value in itself, i.e. intrinsic value. Seen in this perspective, play is something people at any age spend huge amounts of time on solely for the fun of it, e.g. as physical play, sport, stories, jokes, games and celebration [96, 6]. The rhetoric also points out that the motivation derived from play is intrinsic and, perhaps most importantly in regard to games for health and rehabilitation, the reward is instant (we will get back to that later).

The point of Sutton-Smith's review of the rhetorics of play is to highlight that play is not a homogeneous concept. There are many diverse understandings of what play is and why we play [95]. It is essential to be aware of the rhetoric being used, as this is often unspoken and, thus, partially hidden, but the understanding of play has a vital influence on the directions and perspectives of research and development done within the field. This is also part of the reason for reviewing Sutton-Smith's rhetorics here, as this thesis adheres to the understanding of play as something valuable in itself, with intrinsic motivation, and, thus, a part of the rhetoric Sutton-Smith calls "frivolity".

This choice of rhetoric and understanding of play is based on the understanding which the following theorists present about what play is and how we must understand it. Further, it is fundamental for the research done in playware [6, 11]. In this context, it should be mentioned that Sutton-Smith emphasizes that the terms "frivolity" and "silly" are names other rhetorics articulate for this kind of understanding of play, because this kind of play from their point of view is perceived as pointless [95].

3.1.2 The magic circle

One of the founders of the modern understanding of play, who also plays a central role in contemporary game research [97], is the Dutch historian Johan Huizinga, who in the 1930s studied play as culture. His major work "Homo Ludens. A Study of the Play-element in Culture" [96] points to the fact that a key feature of human beings is that we play. In this book, Huizinga highlights that play has value in and of itself, not to be justified in the external rational understandings, such as can be seen in the understanding of play as development. Huizinga subscribes to the understanding of play as frivolous, and he emphasizes that play is irrational. This irrationality is even part of the attractiveness of play [96].

Huizinga emphasizes that play is a voluntary activity, and as soon as we are forced to play, it is no longer play [96]. He further stresses that we have a fundamental need to play that cannot be justified on other grounds than the joy play offers. This is also the reason that play is a voluntary activity [96].

According to Huizinga, play is characterized by being something other than our normal lives, and he gives play its "own space". Huizinga describes play as stepping out of our normal world and into another sphere or into "a magic circle" [96].

Inherent in the concept of the magic circle is the understanding that play takes place in a delimited space and time. Often the delimited space can be of a physical nature, but it can just as well be a mental delimitation [96]. An example of a play-place is a playground, where the borders of the playground also represent the delimitation of where the play activity is happening. But it may also be more abstract, as in the case of online games. Huizinga outlines how play involves temporary worlds within the ordinary world, which are dedicated to the playing [96].

Another element of play and the magic circle is that there are always rules, and if the rules are broken the magic circle breaks. Huizinga sees play as a fragile construction that may collapse at any time if the players break the boundaries or rules that exist in the play world. As such the worst thing for play is rule breakers or cheaters, because they destroy the illusion inherent in play - the magic circle [96].

While the understanding of "the magic circle" has often been, and still is being, debated (e.g. [93, 98, 99, 100]), Huizinga's concept gives play its own place and meaning. We will not go into the details of this ongoing debate, but focus on the point that play is voluntary, separated from normal life in some way (you can be a killer in play without facing the consequences of real life), and finally that it is a construction that can collapse at any time [96]. The understanding that different rules apply inside and outside the magic circle is what we will look at in the next section where the concept of framing will be presented.

3.1.3 Framing

The understanding that play is in some way delimited from ordinary life is part of what Gregory Bateson, a theoretician of communication and cybernetics, has studied. Bateson points to a paradox in the concept of play. Actions in play do not denote what they normally would denote in other situations or what he calls "frames". He highlights in his text "A Theory of Play and Fantasy" [101] that play puts forward a special framing of a situation in which the action carried out is not to be understood in the way it would normally be understood. He introduces the terms framing and meta-communication to understand how actions of play can be perceived differently than other actions, or how the same action in different "frames" can be interpreted very differently. This is in tune with Huizinga's thoughts about the magic circle.

Bateson's example of how to understand this framing has been quoted many times in play and game research [94]. He observed two monkeys in a zoo play-fighting. One tries to "bite" the other and this, in itself, could be considered an attack. But Bateson points out that, along with the action (the bite), there is a meta-communication which stresses that "This is Play" [101]. The bite that would normally be interpreted as an attack should instead be understood in a special play-frame. The playful bite should, therefore, be understood as part of a play, and when it is interpreted in this frame, it is not a real bite, but a play-bite. As Bateson formulates it: "The playful nip denotes the bite, but it does not denote what would be denoted by the bite." [101].

The concept of framing is central in Bateson's work, and he emphasizes that framing is a psychological concept that defines a set of meaningful actions. He also points out that a frame has a degree of physical existence without being purely physical in nature. This is also illustrated in language, when we talk about "an interview" or "a meeting". These meetings or interviews are a limited set of meaningful actions, and we can talk about a framing of them [101].

Bateson uses the picture frame as an analogy for the psychological frame and emphasizes that a framing of a situation has the same effect. A picture frame delimits something from the rest of the world so that we, as humans, can filter the rest out, and that is exactly what is characteristic of framing. In that connection, Bateson presents a number of typical features of psychological frames.

First, they are exclusionary and inclusive. Framing creates a boundary so that there is something inside the frame and something outside it. The framing suggests that we should attend to what is within it and not what is outside it [101].

Secondly, we should use a special interpretation within the frame, which is different from the one we use outside it. As with a picture frame, psychological framing tells the recipient that they will need a special way to interpret the contents within the frame (e.g. the picture) in relation to that which is outside the frame (e.g. the wall) [101]. This is particularly noticeable in relation to play, as pointed to earlier. Actions in play should be interpreted in a different way than actions taking place outside it. At the same time, the framing gives instructions on how the content of the frame should be interpreted, e.g. "This is Play" or "This is Art".

Finally, there are rules for interaction within framing, and these rules may be subject to changes. The rules of framings, and as such, also in play, should not be understood as something constant and unchanging, but as something more or less dynamic, which at least have the possibility of being changed over time.

From the above, we can conclude that play is framed in certain manner and that a meta-communication is taking place, telling those involved that this is play, and the actions that take place therein should be understood in a playful context. This is evident when we see children playing, but also in adult play such as jesting, where it is clear that the actions carried out is not to be understood in the same way as normal.

As with Huizinga, we can see that play according to Bateson contains rules for how we can interact if the play is to continue. Bateson points out, however, that in the frame the rules are not rigid, but can to some extent be subject to changes. Again, this is very evident in children's play, which constantly talks about how the game should be understood and pursued, e.g. by terms such as "Let's say that...".

The framing concept enables an understanding of how play may establish and create its own world (the magic circle), a world that must be understood in the particular context it occurs in. Play cannot be understood independently of the context in which it takes place, precisely because there is a unique framing of the situation. Therefore, it does not make sense to interpret play without also interpreting the particular situation it takes place in.

With Huizinga and Bateson, we reach an understanding that play takes place in a unique separate sphere that is not subject to the same frame of interpretation as the rest of our lives. This is central to the understanding of what play is. In the following we will look at different kinds of play, to further understand what play is.

3.1.4 Categories of play

Play can take many forms and occur in many different ways. Therefore, when we talk about play it can be an advantage to categorize these forms. In the book "Man, Play and Games" [102], Roger Caillois draw up a classification of different types of games. As both Huizinga and Bateson do, Caillois also points out that play is voluntary, and he emphasizes that it is unproductive. It creates no wealth or goods, unlike, say, work or art does. Play is, according to Caillois in essence an occasion of pure waste [102].

Although Caillois agrees with Huizinga that play is something separate from the rest of the world, and that play is the purpose of play (e.g. not learning or other extrinsic goals), Caillois also criticizes Huinzinga's understanding, as it excludes gambling and games of chance. To deal with this, Caillois splits play in to different types and four general categories, which in his opinion are adequate to cover all the types of play that exists. It should be emphasized that Caillois sees a strong link between play and games. The four categories are: Agôn, Alea, Mimcry and Ilinx.

Caillois believes that there is a great variety of play that deals with competition, and these he categorizes as Agôn. In Agôn the goal is for the participants to get recognition for their superiority in an area of competition. Examples of Agôn play are racing, playing soccer and chess.

Alea is Caillois' second category. These are types of play where chance and luck are in focus, and the winners of these kinds of play are those who are "lucky". The participants are passive, and here Alea is opposed to Agôn because Alea play negates experience, qualifications, work and patience [102].

In Alea we have the category that Caillois criticizes Huizinga for ignoring and excluding. Although these games may seem serious and productive, Caillois emphasizes that this is not the case, by stating that playing for money remains completely unproductive, as the players are not producing anything [102].

It should be noted that gambling can quickly go from play to seriousness, e.g. when it is no longer possible to leave the game, as with a gambling addiction. Play is, as stressed earlier, characterized as a voluntary activity, thus, this shift would take it out of the category of play, according to Caillois [102].

The third category is play where the players "pretend". Caillois calls this

Mimicry. He stresses that all play is about the participants accepting a closed and imaginary universe in one form or another (i.e. Huizinga's magic circle). An example of Mimicry is theater [102].

Unlike Agôn and Alea, which are characterized by precise and imperative rules, the rules of Mimicry are more free. Mimicry is more about fiction and immersion. Caillois points out that it is from within the immersion and fiction that we get the pleasure of Mimicry, as we can be someone else [102].

Finally, the last category is Ilinx. This category includes play that runs on the sensation of dizziness, including various physical activities that create similar feelings, such as skydiving and rides in the amusement park (carousel, slides, etc.). Caillois points out that this sensation of dizziness is not only a physical entity, but it can also be a vertigo of moral order; a vertigo that is linked to a desire for disorder and destruction, a desire we normally repress [102].

As there are varieties of games within each of these four categories, Caillois creates a scale to rank the different games internally in each category. This scale has two poles, which he calls paidia and ludus. Often these concepts are understood as play with rules (ludus) or without rules (paidia) (see, for instance, [103]). Caillios introduces paidia as an almost indivisible principle that manifests as a kind of uncontrolled fantasy, while in the other extreme, ludus, the paidia is almost completely absorbed and disciplined [102].

Caillois stresses that the scale applies in all of the four categories, rather than being two new categories. Thus, the different play examples in each play category are more paidia than ludus or vice versa, but both are still one and the other to some extent. According to Caillois play always contains both the free element that constitutes paidia and the more disciplined ludus, often through rules that can be more or less rigid [102].

In Caillois' understanding of play as presented here, we find a clear focus on the goal of play, such as in the category of Agôn where the goal is to show superiority, or in Alea where the aim is to be "the lucky one". The Agôn category and Caillois' understanding of these types of play brings us back to Brian Sutton-Smith's rhetoric of play as power, not least because Caillois emphasis the importance of the goal of the game. Therefore, although Caillois' classification of play is probably the best composed, a criticism is that it is orientated towards the idea of the goal of play.

As we shall see in the next section, when it comes to play, it is not the goal but the means that is important [104].

3.1.5 Play and arousal

In the book "Adult Play" [104] Michael Apter presents play as a special mental state. Together with John Kerr, Apter has developed what the team call the "reversal theory" [105, 106, 107]. Central to this theory is the idea that when we are in the playful mode we feel safe. Apter presents it as a protective frame, and points out that we are in this frame when we not only feel safe, but also have nothing we must do. Apter calls this the “paratelic mode”, and when the protective frame is gone we are in the “telic mode” [104].

Apter compares the paratelic mode with a playful state, while telic is when we are serious. More specifically, we are in the telic mode when what we do has significance beyond the current moment [104].

Apter emphasizes that the protective frame comes and goes in the course of our normal everyday lives, or, rather, that we "reverse" between the telic and paratelic mode, thus the name "reversel theory".

Apter sees play very much as fitting into the rhetoric that Sutton-Smith calls frivolity. Means and goals are, for Apter, key when we want to understand the distinction between telic and paratelic. In the telic mode, the goal will determine the means. Here, we choose the means to achieve an end, and it is thus a goal-oriented state. In the paratelic state the situation is just the reverse. Here it is the process that is most important, and not just the end in itself. Therefore, when we find ourselves in a playful state, we can lose a game, but not feel that we have wasted our time. In the paratelic mode, the outcome is less important. However, Apter emphasizes that often playful activities have a goal, for example in races- and sports games, but that these have the effect of creating or enhancing the enjoyment [104].

Apter further points that the paratelic mode is characterized by a willingness to experiment and mess around. It is about engaging in pretense and make-believe, and in this state we put the emphasis on immediate gratification and a seek to prolong the activity whenever possible [104].

Finally, Apter stresses that a key point is arousal. He emphasizes that in the paratelic mode we are searching for activities that can create high arousal, while when we are in the telic we are trying to avoid these [104].

We can get high arousal from, e.g., frightening experiences. In the paratelic state these feels "pleasant" and is something we often seek. An example could be going to the cinema and watching a horror movie. If, on the other hand, we are in the telic mode, e.g. on the way home on a dark evening, the same frightening experiences are unpleasant.

Apter uses the metaphor of a tiger and a cage to illustrate the point. A tiger without a cage creates anxiety (danger), a cage without the tiger creates boredom (safety) while a tiger in a cage creates excitement (danger-within-safety) [104].

Apter also identifies seven psychological strategies that can be used to create a high level of arousal [104]:

1. Exposure to arousing stimulation. This could be exposure to music or bright colors, but also elements that are arousing because of their biological meaning (e.g. blood or a naked body). Apter also explains how elements that have properties such as incongruity and complexity can create arousal, because they provide interest and amazement.

2. Fiction and narratives. For example identifying with the hero or their emotions as terror or grief.

3. Challenges. E.g. sports competitions.

4. Exploration. E.g. exploring new territory of any kind.

5. Negativism. Deliberate and provocative rule-breaking, regardless of whether it is explicit regulations being broken, or implicit social rules.

6. Cognitive synergy: Apter describes this as a concept in reversal theory and defines it as an experience with incompatible properties. This could be for a person, place, situation or thing.

7. Finally, the last of the strategies he presents is the perception of danger, especially if we are in a safe setting, such as is illustrated in the example of the tiger in a cage.

In the above, we see that Apter looks at play as a special mental state called paratelic. In this state we are seeking high arousal, while when we are in the telic, i.e., more serious state, we try to avoid elements that create high arousal. In this context, Apter points out that when we are in the paratelic state we are in a protective frame, and this frame makes us feel secure, so high arousal can be a positive experience.

3.1.6 Play and Flow

Lastly, we will take a look at another theoretician, who is famous for introducing the concept of “flow”, that in reality is another way of describing playful experiences in much the same way as Apter does, even though the theoretician responsible, Mihaly Cziksentmihalyi, uses another word. Interestingly, especially in the light of the rhetoric of play as frivolity and silliness, Cziksentmihalyi told a story about why he invented flow as a concept [108]. This was not only because he wanted to focus on adult play, but also because it made it easier to achieve funding for his research.

“Flow” refer to a specific state of being in the world that Cziksentmihalyi characterizes as “optimal experience”. It is a state where we become so involved in our activities that we forget time and place. Reality is set aside while we are completely absorbed in what we are doing. Cziksentmihalyi refers to these activities as “autotelic”, which means that the goals are intrinsic.

The characteristics of flow are, in principle, very similar to the characteristics of play, but compared with the theoreticians above, Cziksentmihalyi expands the concept of flow beyond what we normally see as play, because, according to him, “flow” is something we can experience everywhere and in any context, even while we work. One of his examples is surgeons, another is mountain climbers, who, according to studies by Cziksentmihalyi and associates, often forget time and place and “flow” in their activities like in water. And, finally, it is important to note that this way of being in the world is a state that many strive for.

This description of flow is taken from interviews Cziksentmihalyi conducted with people from different professions [109]. While the concept of flow does not add to the concept of play outlined above, it is of interest that flow can be uncovered via empirical studies.

Today flow is an important part of so-called positive psychology, where the concept is often referred to as “the zone”, which inevitably brings Huizinga’s “magic circle” to mind.

3.1.7 Summary of 'What is play?'

In these sections I have explained some of the understandings of play that lead to the concept of play, which is important for playware research. Based on Brian Sutton-Smith's rhetoric of play, it is important to understand that play and games can be viewed and discussed in many different ways. While in western modern society, we often encounter play as development or creativity, the presented research shows that play can be seen as what Sutton- Smith calls frivolity. It is this understanding that underlies the studies in this thesis. The basis for this theoretical analysis is that the game carries its purpose in itself, and that it is an experience we strive for, and will even do a lot to reach, such as in the example of a mountain climber. Play cannot be justified by external factors, and, as Johan Huizinga emphasizes, play is something that is separate from everyday life. He uses the term the magic circle, and Gregory Bateson's notion of framing further reinforces this separation. Michael Apter expands on the understanding of what play is by introducing the concepts telic and paratelic, which are two different states we may find ourselves in. In particular, Apter stresses arousal as something we seek when we are in the paratelic state, while it is something we want to avoid in the telic state. Cziksentmihalyi empirically confirms the existence and attractiveness of playful experiences.

Following the theoreticians above, we can say that play is a special *state* we can be in, the play state [97]. In this state we look for stimuli that can give high arousal and we use numerous ways to reach that state, including what we can denote "tools", like games and play equipment. The quest for the play state cannot be justified by external reasons, such as learning on the contrary, it is an end in itself. Lund and Jessen have perhaps presented the best definition of this concept of play [110]:

> "Play are actions that we perform or participate in, with the aim to create a reality sphere in which we are free and undisputed can create and regulate moods (physical and mental states), which gives us specific, desired (delightful) experiences, socially and individually." (Translated from Danish from [110])

It is this definition that we will continue to work with in the following, where we turn to research on games, toys and technology as tools for creating play. The goal here is to reach an understanding of how these tools work. In an attempt to do that, we have developed a new perspective on games as "actors" that can do something to us, as users. This perspective is grounded in Actor Network Theory (ANT) [111, 112], and will be presented below.

3.2 Games as Actors

The following is a presentation of the findings od paper D, "Games as Actors", that develops a new perspective on games based on Actor Network Theory (in short, "ANT") [112, 113, 114, 111], as developed by Michael Callon and Bruno Latour [115]. A deeper look at this theory or methodology can be found in the paper and the following is a short presentation. We will also here look at some of what this brings to the amalysis process when we look at games.

In ANT, all analysis of situations is done on the basis that everything consists of actors and networks. Furthermore, both human and non-human (e.g. technology) are treated equally in the analysis. This means that humans are not considered the only actors in a network [112], which is the point where ANT fundamentally differs from other social theories where humans are considered the active subject.

This view of non-humans as actors can be difficult to grasp and sometimes even counter-intuitive, but Latour points out that if we want to understand how and what kind of actions technology (in a broad understanding of the concept) can do, we need only to think about what kind of work we would have to do if the technology did not exist [113].

If we accept this view on technology as actors who can do a piece of work (e.g., open a door automatically), then we can also accept the view that we can transfer agency to technological objects by making them able to do things. Transferring agency to a non-human object is the focus point of the paper, as we are trying to understand how games work or act upon human players. In that perspective, games are not just items we use and control, but a phenomenon that puts us in a certain position and takes "control" over our mind and body, when we follow the rules and do as we are supposed to as players. It must be stressed that this "control" we give up is something we do willingly. We are, so to speak, giving in to the game by accepting the rules and our own role. In return, we get to go into a play state. This is easy to see when we enter a technological machine like a roller coaster, which literately takes control over our body, but the same can be said to happen when we enter into the role of player of a game.

The way we transfer agency to a non-human object (or human, for that matter) is by delegation, or what in ANT has been termed "translation" [116]. While we will not look at this process here (it is thoroughly described in paper D), the point to understand is that we do not hand over control of our self in the course of delegating agency. To delegate is more to act as prescribed in order to achieve a goal (e.g., come from A to B, or get into the state of play) [4].

On the basis of ANT, the paper looks into three different types of games and the actor networks associated with this -a board game, "Quackle!", a computer game called Grand Theft Auto V, and the MOTO tiles. The goal is to understand what games do when we accept that we will play them, and how they make us get into the state of play. To understand how games act upon us as humans and, by that, bring us into a state of play, is an important precondition for designing playware that works.

The analysis in this paper shows that the way games are designed means we can allow them to take over our body and mind, and the games can utilize this to make us act in certain ways. Again, it is important to stress that this only happens because we as players accept the terms of the game.

The use of ANT to understand games and how they work on us have implications for games (and play) design. First, it is important for designers to understand how they design social actors (games) that can take agency and build networks that can push the players into a state of play (we will return to this in the next chapter as well). Second, the designers should know how to create arousal (as presented earlier around the work of Apter [104]). Third, the designers need to set the framing of the situation (as presented from the works of Bateson [101]). Framing the situation can be done by setting the scene (e.g. through narratives or other means), that convinces the players that they should invest time and energy into engaging with the game.

Lastly, the paper also presents the notion of "scripts", taken from Madeleine Akrich [117]. Scripts can be understood as a form of small manuscript (taken from the world of movies), guiding how we should act in certain situations. These scripts can be "downloaded" to the individual when we learn them from others or from technology. One example of this is when small children learn from older children that they should dance when there is music, but they are also very common in the form of tutorials that teaches us how to interact with, e.g., a computer game.

The above presentation is developed further in the following chapter, which takes as a starting point the work of Lund and Jessen and their concepts of play force and play dynamics [118]. The chapter presents some of the unpublished findings of this thesis: A Theory of Play Dynamics. Let it be noted that the following chapter is structured as a separate paper, not referring directly to other parts of the thesis, as it is the intention to publish these findings. This is also the reason why there is repetition of points and explanations from above and from paper D for which I apologise in advance.

Chapter 4

A Theory of Play Dynamics

Abstract: In this paper, we will present a theory of Play Dynamics. The effect of Play Dynamics is to push the user into a state of play, which we define as a way of being in the world, where we have a specific framing and a certain disposition towards the world and the actions done. We believe that humans play solely for the fun of it, and that they use tools for play (toys, games etc.) that depend on Play Dynamics to push them into the state of play. In this paper, we will present examples of how Play Dynamics work in well-known play tools from physical games to computer games. We believe that the notion of Play Dynamics brings a better understanding of why certain play tools work better than others, and what it is that makes them work. *Keywords: Play, Play Dynamics, Games.*

4.1 Introduction

“Play” is a somewhat fluffy concept, which is often implicitly defined in academic research. We agree with the grand old man of play research, Brian Sutton-Smith, when he summed up more than 40 years of play studies by writing:

“We all play occasionally, and we all know what playing feels like. But when it comes to making theoretical statements about what play is, we fall into silliness. There is little agreement among us…” [119]

We do not pretend to end the silliness in this article, but in the following, we will attempt to clarify how the concept of “play” can be better understood regarding products designed for play such as play equipment, board games and computer games. We will present a theory of "play dynamics", taking our starting point from humanistic play theory and philosophy.

Games, especially computer games, have lately obtained attention in scholarly research as a research area in itself. Because we understand games in relation to play to avoid misunderstandings, we will start by explaining how we see the relation between games and play. We will start with the French play theoretician Roger Callois' concepts of "ludus" and "paidia" [102]. The two concepts are often defined as highly structured and unstructured, respectively [120]. In that sense the two concepts are defined on a horizontal line as two different versions of the same thing, which is some kind of activity. Contrary to that, we define the two concepts on a vertical line where games are a subset of play. Even more so, we regard games as a tool that we humans use to create play. From that perspective, games are only one phenomenon among innumerable others with the purpose of being a tool that humans (of all ages) use to get themselves into play, which we see as a specific state of being in the world. In the following, we will explore this state of being as a first and very important step, in presenting our theory of play dynamics.

4.2 Play as a state of being

We base the understanding of play presented briefly above on the play theory of philosophers as Johan Huizinga [96], Gadamer [121] and Sutton-Smith [119]. Huizinga is the most well-known example of a wide range of play theoreticians who followed the German philosopher and poet, Friedrich Schiller, who is famous for the line: "...man only plays when in the full meaning of the word he is a man, and he is only completely a man when he plays...", written in 1793 [122]. In this tradition, the understanding of play is far from the one that dominates psychology and pedagogy nowdays, where play is first and foremost a means to an end in the development of children [123].

Perhaps the main reason why play is a difficult concept to define in an academic context is that it represents other values than science normally does. In science, researchers usually try to rationalize human activities by giving them a purpose.

According to Huizinga play does not submit itself to the usual rational notions. In his famous book “Homo Ludens" (or "Man as player”) [96], he writes:

"... The fun of playing resists all analysis, all logical interpretation [...] Here we have to do with an absolutely primary category of life, familiar to everybody at a glance [...] We play and know that we play, so we must be more than merely rational beings, for play is irrational." [96].

Huizinga describes play as a separate life sphere that cannot be legitimized with external purpose. Play is a self-sustaining phenomenon, which carries its purpose in itself. Compared to other human activities, it does not lead to anything; it neither creates nor produces anything, except, precisely play:

"Play is a free, voluntary activity indulged for its own sake, and although creative, play is unproductive and non-utilitarian. Play has boundaries of space and time, and takes place temporarily outside ’regular life,’ with its own course and meaning." [96].

Accepting this line of thinking about play as something that is not rational in a common sense, a cencept which Huizinga shares with some of the most influential thinkers in modern philosophy (e.g. Nietzsche, Heidegger, Caillois, Gadamer, Derrida), turns most accepted wisdom around human behavior upside down and pose a difficult question: How are we to explain human activities without referring to rational reasoning?

The claim that play carries the purpose in itself must not be understood as a statement that suggests that play is a meaningless act. Even though a great deal of the play activities which humans engage in often can seem meaningless (especially when you are not participating), it is an important point that play is the purpose of play. The German philosopher Hans-George Gadamer, who explicitly takes his point of departure in the concept of play, says it like this: “[Play] may be a purposeless activity but this activity in itself is intentional.” [121].

Huizinga describes play as something that takes place “temporarily” outside ordinary life, in what he calls a magic circle [96]. This magic circle has a great overlap with what Gregory Bateson has termed framing [101]. Framing is a linguistic and psychological concept that both delimits a set of meaningful actions like a picture frame (“Attend to what is within and do not attend to what is outside”), [101], and at the same time gives instructions as to how to interpret the actions within the frame. Bateson formulates it in this way after describing how he observed two monkeys play fighting: “The playful nip denotes the bite, but it does not denote what would be denoted by the bite.” [101]. This means that when we play, we are in a special sphere, and we can only understand and react to the actions we take within this sphere. When participating in play fighting, children do not fight for real. It is a violation of the tacit rules of play if they do.

Michael Apter further elaborates when he states that it is a fundamental concept about play “that it is a state of mind, a way of seeing and being, a special mental ‘set’ towards the world and one’s own action in it” [104]. In other words, play is a state of being in the world; a state where the regular rules do not apply, because in the state of play, we can do and say things without the consequences they would normally have, and we can imagine things that are impossible in ordinary life. The actions we undertake are framed as play and participants have a playful attitude towards the world and the actions done within this framing. All that is a well-known fact about play, but the question is, why do humans act like this? What is the purpose within the purposeless?

Huizinga states we enter the state of play “for the fun of it” and in the same manner, Michael Apter writes that we choose to play “for its own sake and the immediate pleasure which you hope it will bring” [104]. A few examples can illustrate what that means. One of the games small children play is the game of making themselves dizzy by whirling around. Observing children getting dizzy in this way makes it clear that it is an exciting experiment and very funny, even though the child falls down repeatedly. For the child, there is no reason for playing the game other than the special feeling it creates in the player’s body and mind. The same is the case for other activities like using a swing, playing ball, playing golf, dancing, playing computer games etc. and for the games parents play with infants like tickling on the changing table, which Sutton-Smith has called a “paradigm” or an archetype for play:

"... we postulate as the original paradigm for play, mother and infant conjoined in an expressive communicational frame within which they contrastively participate in the modulation of excitement. We call this a paradigm for all lucid action, because we suggest that other play itself is a metaphoric statement of this literal state of affairs." [119].

This description of play as an active modulation of moods from the players' point of view is quite a precise definition of what happens when we play, regardless of age. Thinking along those lines, Lund and Jessen have defined play as follows: play is actions which we undertake and participate in with the purpose of creating a reality-sphere within which we are free, and which can independently create and regulate moods (physical and mental states of tension) which provides us with specific, wanted experiences (of delight), socially and individually. [110].

4.3 Tools for play

Lund and Jessen's definition implies that active effort is a premise for play, and in their paper they point to the fact that throughout our lives we develop the ability to modulate moods and they emphasize that we use tools to do so.

Play does not come by itself. It demands effort, work, knowledge, and, not least, learning. Play is a state the players create with purpose, and, thus, play is a goal-oriented, intentional human activity. We use countless methods to achieve the state of play, and knowledge of those methods and competencies in using them are indispensable if one wants to play. Apter expresses it this way:

"One of the most interesting things about play is the tremendous variety of devices, stratagems and techniques which people can use to obtain the pleasures of play" [104].

We could add that it is likewise interesting what great economic investments people are willing to make to obtain playful experiences.

Some of the methods to achieve play we know for example, games, which we either learn from parents, peers, etc., or buy, as with board games and computer games. Other methods are embedded in play equipment by designers, like the swing or the roller coaster. We can describe both play equipment and games as instruments or "tools" that are specialized in order to create play, and when someone uses these tools, they assist in creating and regulating those physical and mental states of tension and moods that we defined as play above. For example, by following the rules of a street game, there is a good chance the players will experience the state of play. Umberto Eco expressed it like this in the Italian introduction to Huizinga's book "Homo Ludens" [96], cited above:

> "To play the game" means "follow the rules". There is an abstract subject, a game, and then there is concrete behavior, a performance of play. To play is "to take part in a game." (taken from [118]'s translation from [124]).

In their book on games and play, “Rules of Play” [93] Salen and Zimmerman identify a similar connection between games and play. They define the goal of successful game design as “the creation of meaningful play” and later on state that “rules are merely the means for creating play” [93]. To make their central point absolutely clear, they argue in a subsequent anthology on games that “Games create play: of that there is no doubt” [93]. In other words, games fulfil the function of generating play when in the hands of users. That is the sole purpose of games.

4.4 State of play

So games help users to create play, but we still need to have an understanding of what we put into the concept of play. Based on the exposition above, we will describe play as a special state that we as humans seek to get into the state of play. To understand the concept, it is important to distinguish between what we normally term ‘playing’, and the process of getting into the state of play. Activities we label as play are often an ongoing search for the state of play, and the experiences this state entails, which are not always successful.

The search for the experience of being in the play state is evident from our empirical data on children’s play. The children we observed tried out toys and often they ended up packing them up again and trying something else. This is more evident among small children who are still developing their play abilities and play culture, while older children have a more developed sense of what they want to play and how to do so, and thus don’t have to search as much as the younger children. We even see this among grown-ups and elderly, who express it as, e.g., “being in mood for” a horror movie or comedy respectively. They know, more or less, what will work for them right now that is, what will get them into the state of play.

What mood we are in emphasizes another important part of play, which is best described by Pierre Bourdieu's concept of habitus: embodied experience, reaction and action which determine what we think about, what we resent, and what we do not respond to [125, 126].

We all have dispositions for what we like and what we react to, and these are in constant development. Whether a certain toy or as denoted here, a "play tool" is working is a question of taste and habitus. There has to be a connection between what tool the players use to get into play, and the habitus the players have. For this reason, play can also be very different from culture to culture and among individuals. In general, it is vital that the play tools we use work right here and now, and that they create the right sensation in the user's body or mind. Otherwise, they fail, and the player will not achieve the state of play.

Let us be clear: getting to the state of play is not an easy task. All play demands (often hard) work in order to be successful. Apart from the state of play being the successful result of a goal-oriented experimentation and search, we also understand it as a special state, where we experience the world in a different way. The framing of actions tells us to have a certain disposition towards the actions, and here it is the process and not the end goals that are of importance [96, 104, 101].

All in all, this boils down to the fact that the state of play is a combination of a special way of being in the world, where we have a certain framing and disposition towards the world, and the actions done. We are seeking out some kind of special stimulation that can push us into the state of play, which creates the feeling of joy within us.

4.5 Play dynamics

Games are especially good at creating this feeling within us, and they have "tacit knowledge" of methods for creating specific play experiences embedded within them. Often, that knowledge is cultural heritage, handed over from generation to generation. In modern times, where street play culture and other traditional cultural activities are vanishing, there is a need for new tools for play, tools that we can adjust to modern conditions [14, 29, 11, 97].

If we wish to create play tools, whether it is computer games, playgrounds, or toys etc., it is important to have an understanding of which games and play products will function properly by generating play for users, and why some function and others do not. We claim that we can gain this understanding by studying what we call “play dynamics”. These dynamics are a wide range of phenomenon that have one thing in common: when we invoke and use them, they normally place the users in a state of play. The rules in computer games are examples of play dynamics, but there are numerous other kinds of dynamics, from whirling in circles to the competition that is part of playing chess.

In the following, we will analyze examples of these play dynamics, and how different play tools use them. It is not our intention to create an exhaustive list of dynamics, which we believe would be impossible in itself, as the dynamics are continually developed along with our play culture. But we believe it can be beneficial to understand what dynamics are at play when we create toys, games and other entertainment sources. By researching and understanding what works and how, we believe we are creating a new research area and a new methodology for discussing and developing toys, games and play equipment.

We have already described one play dynamic above, dizziness, which is a specific kind of reaction in the body that is brought forward and controlled in a game we could name ”body whirling”. The dynamic only involves producing the feeling of dizziness, but that seems to be a very common way to get into the state of play. Children are not the only ones to use this dynamic we also see it throughout life in various settings such as amusement parks.

Another example is the game of tag, where the play dynamic is to chase and to be chased. In the same way as body whirling produce dizziness, tag produces a specific kind of feeling in the body based on controlled fear. If you remember the game, you will also remember the feeling the body produces when you are nearly caught and tagged. In that situation, it feels like the body is taking over and reacting as per instinct, which produces a state of joy when you succeed. When it works best, the play dynamic of tag is an ongoing movement between nearly being caught and getting away.

To illustrate how play dynamics can function we will describe a board game called “Quackle!”. We have chosen this game, as the situations we observed are

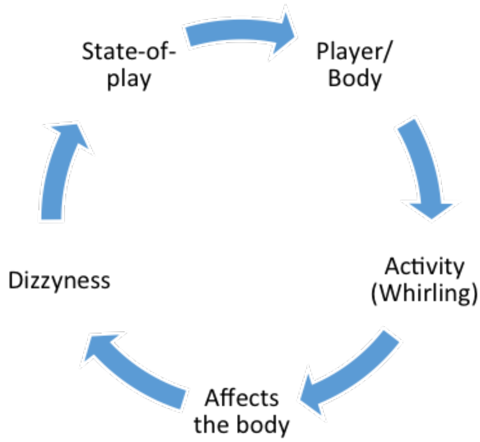

Figure 4.1: An example of how the play dynamic of whirling create play for the user.

exemplary for what we see in other play tools, and because this game only uses a limited number of play dynamics. This is part of the challenge, when we try to understand how a play tool works; often they combine a long list of play dynamics in order to create the effect among the players. This is especially true when it comes to play tools created for experienced players, as they continually demand new challenges and inputs.

4.5.1 The board game "Quackle!"

The case of playing the board game "Quackle!" in a mixed age group is an illustration of play dynamics. We will here give a very brief description of the game, and refer to the manual for a more thorough understanding of the game [127].

Quackle! is a board game for the ages 5 and up. The game consists of 12 different animal figures, eight barns and 97 playing cards with pictures of the animals. In short, the gameplay functions like this:

The players pull a random animal figure from a cloth bag and after showing it to the other players he or she hide it away in a barn. A player deals all the cards to the players and place them in a pile in front of each player face down. The objective of the game is then to get rid of all the cards you have.

The game runs in rounds, where each round consists of the players turning a card over and placing it somewhere for all to see. If two cards with the same kind of animal are turned over, the two players who have the same animal on their card enter a battle. Here the players have to be the first to say aloud the sound the animal in the other player's barn typically makes ("oink" for a pig, for example). The player that loses the battle gets the other player's card. The game continues this way until one of the players gets rid of all their cards.

The game seems pretty simple, but requires that players can remember and quickly say the correct sounds when two identical cards are turned, which is more difficult than one might think -even for adults.

As described above, the game expect the players to interact in a special way with it. This is where we find the use of play dynamics. In the following, we will analyse some of these dynamics at play in the game.

First, the game uses a play dynamic of mixing many things and making it hard for players to keep them all in order. When the players play Quackle! they get a lot of inputs in the form of different animals (their own animal, the other players' animals, the animals on the cards), and they have to remember what is where.

Another dynamic is competition; this is probably the most common dynamics in games. The players have to compete against each other, and this is important for the game to work, as it brings the dynamics of multiple inputs from above into effect. As with other competitive games, a tension is built up in the players that is especially apparent among children, but also present among adults.

Keeping an overview of the different animals is not that hard, but when we combine it with the competition, the players have to be as fast as they can. Thus, it is no longer just the test of remembering animals and their associated sounds, but also be the first to say it aloud.

The game also uses a social play dynamic. The dynamic utilizes the effect of people saying something wrong in the company of others.

The fun in the game occurs when players say something completely wrong. By combining, the above mentioned three dynamics, Quackle! unavoidably forces the players to produce a wrong and often strange sound in a social context, which creates laughter, and pushes all players into the state of play. Because the player has to be very fast in competition with others, they will often not only say the name of a wrong animal, but they will have difficulties pronouncing the name at all. Their tongue will not obey, and instead of a specific sound, strange sounds will unintentionally come out of the mouth. In other words, the game affects the player physically, much in the same way as whirling around does. This way of influencing users is prototypical for play dynamics in games and other play tools.

While we can find other dynamics in this game, we believe that this analysis is enough to introduce the way of thinking behind the theory of play dynamics. We will now continue to another example of play dynamics and make a brief analysis of the highly successful computer game, “Counter-Strike”.

4.5.2 Counter-Strike

Counter-Strike was developed as a modification of Valve’s "Half-Life" and has been and continiues to be a highly successful game. Since the first release in 2000, several follow-up games have been created and the latest from 2012, still has over 6 % of total playing time across all games as of 2015, making it the second most played PC game [128]. In the following, we will focus on how the game pushes the player into the state of play by the use of play dynamics. First, we will give a brief description of a game scenario, followed by an analysis of this scenario, and then we will move on to our goal of understanding the play dynamics in the game.

Briefly described (more information can be found on Wikipedia), Counter-Strike is a first-person shooter game, where the players see the game world in first-person-view on the computer screen and see their co-players and opponents as figures. Participants can play on teams as either terrorist or counter-terrorist. Each team will try to either kill all the players on another team, or complete their mission objectives. The most common setup is that the terrorists must carry a bomb, plant it in one of the designated spots, and protect it from the counter-terrorists who will try to disarm it before it explodes.

Counter-Strike resembles the traditional childhood game of cops and robbers or cowboys and Indians, that are variants of tag. In Counter-Strike, every time a team wins, the game places the players back in the starting area and revives them if they died during the round. Everyone who did not die keeps their equipment (mostly weapons), while the others lose all theirs. The players start out having only a knife and a pistol, but whenever they kill someone or win/lose, they get money to buy better equipment such as machine guns, grenades etc.

When the game starts, the players move out of the starting area to either protect the bombing area or to try to place the bomb. As mentioned, each player sees the game world in 3D from a first person perspective (as though they are watching through their avatar). They can then move around in the game world, which is a predesigned map of a place (e.g. a train station or an office building), and interact with each other. The game requires a lot of collaboration between the players on the teams and strategic planning.

We observed people playing Counter-Strike and the following is a prototypical play scenario from these observations:

1. At first, the player, named "Jack", has to choose a game to join and then a team. Jack chooses counter-terrorist.

2. After that, the game loads and Jack get ready to play.

3. First, the game displays a loading screen, Jack is placed in "the buy zone" and for a few seconds the game is frozen, so he can buy weapons and other equipment.

4. The game starts

5. All the players run out of the buy zone to different locations on the map. Jack first runs to one of several bomb spots to cover them, which means he will try to keep the terrorist away from the spots by shooting at them and trying to "kill" them. The bomb spots are where the terrorists have to place their bombs. If they do not succeed, they lose the game.

6. Jack hides behind an object (a wooden box) – waiting and looking for approaching terrorists. Jack's teammates and enemies are moving around the map, most of them are sneaking around, hiding behind walls and objects, looking for friends and enemies. Teams communicate, and the voices bear witness to the tension building up. Jack is clearly affected. He is physically restive, moving his head, arms and shoulders abruptly. Occasional messages like "Enemy spotted" come from Jack's teammates, and he can hear gunshots when the teammates get into a gunfight.

7. The first gunfight for Jack begins when he sees an enemy and starts to shoot at him. At the same time, he is trying to avoid the enemy's bullets hitting him. His fear is also visible. He literally ducks his head. He gets hit several times and loses some of his health (shown on the screen). He cries out loud, retreats to a more secure location and calls his teammates for help.

8. After a brief break in the secure location, Jack walks out again and sees everything is clear for the moment, as the terrorist took another route. He starts to search for an enemy again, walking around the map. Then he gets the message "Bomb placed", which tells him that the terrorists have been successful in placing their bomb. Immediately he runs to one of the bombsites to see if the bomb and the terrorists are there.

9. A new gunfight starts. He quickly kills a terrorist with a "head shoot" (and receives a bonus in game cash for this), but shortly after he is killed by another terrorist who comes up behind him. As "dead", he is automatically placed in "observer mode", where he can follow a teammate around and watch him play, but not interfere.

10. A little later, the terrorists kill the last counter-terrorist and the terrorists win the round.

11. A new round starts. Every player gets extra cash to buy weapons.

12. Jack and his teammates, and the terrorist team, play 15 rounds in total before the game is over, and the statistics of the game are presented to tell the players which team won the most times, how many enemies each player killed etc.

4.5.3 Analysis of the Counter Strike scenario

The game has several similarities with street games and sports games. First the player has to choose a side, and the basic question of "what kind of player are you?" has to be answered. This makes the player feel part of a team. In the second step of the game as outlined above, we start to see the tension building up, when Jack is getting ready for what is to come. Often players from the same team will talk about what to do and make the first quick strategic discussions during the short loading time.

By the third point, the players are now inside the real game world. The freeze time makes it more clear what is waiting, and the players are able to see the world, before they start venturing into it. At this point, the player is also able to upgrade their gear and weapons. Getting new and better gear, often specialized gear, builds up the player's expectations. At this point, we also see the network being built between the teammates.

In the fourth point, the players see the game map and the objects within it. Now they are able to walk around, look around and act in the virtual world.

The goal of the game (for Jack), is to win by preventing the terrorist from placing a bomb, and this makes him move to the bomb spot. He wants to see the place and try to find his way around the map.

The fear of being caught makes him hide behind an object. He is afraid that he will be found and shot, and this fear gets more present as he hears messages of teammates finding people, of gunshots and so on. It may sound strange, but even though the "fear" is framed by play and the activity is on a screen, it is obvious that the body is affected. The first gunfight makes it even more evident. Jack's role in the game takes over, so to speak, as he sees an enemy and automatically starts shooting. As the enemy starts to shoot back, he automatically tries to hide and duck (even physically). When he gets hit several times and he flees, it makes the hide-and-seek dynamics clear. The tension of meeting the enemy, almost "dying", and then getting away, makes Jack – and all the other players - go into the game; Jack enters the state-of-play. It is not laugh-out-loud-funny, but nonetheless, a very playful experience. Jack is now fully alert and focused on the game. As he walks slowly and cautiously out of his second hiding place, he discovers that the enemy has taken another route, and he is safe once again to roam around the map. This is also visible physically. His shoulders fall down and he is clearly calmer.

Shortly after he gets the message that the bomb has been placed, meaning that the counter-terrorist team has 45 seconds to find and defuse it (which means he, as a counter-terrorist, has to be fast, setting a time constraint that adds to his tension). He runs to find the bomb.

If we look at the above analysis, we see that the dynamics of competition is dominant, because the two teams compete. The dynamic described earlier in the game of tag is at stake here. In many ways, we can describe the game as an advanced form of tag. Though the settings and ways of tagging and running around are very different from physical tag, it still clearly uses the dynamics of the street game and the way it affects the player's body and mind. By mimicking a well-known game, Counter-Strike pulls on a player's previous experience to get the play dynamic working. The game can build the dynamic up before play even begins in this way, and can then further develop on the dynamic by adding a game world, weapons, and other equipment, and the possibility to talk to teammates and develop strategies. Because of that, Counter Strike renews the experience of ”tag” continuously, and does not get boring.

The underlying play dynamic is the same as the ones we find in tag, hide and seek and the like: the “fear” that is evoked in our body when we are chased, which is probably a deep-rooted feeling in human beings. This “fear” is framed in precisely the same way Bateson points to when writing about apes who are play fighting. Play dynamics do something to our body and mind within a secure frame and thus evoke the mood and state of being in the world that we call play.

With the use of a virtual game world, Counter-Strike further uses the dynamic of emergence, where you experience the surroundings as though they are real, becoming part of the world. Edward Castronova described how this works in his book on synthetic worlds [129], where he explains how we as players who participate in a game can try to pretend that the actions we are undertaking is not real, and neither is what we are experiencing but then, we would simply go crazy. Instead, players surrender to the experience in the game world, and start to talk about the avatar as “I”.

This is an important understanding of videogames that they have been successful in getting the player to feel emerged into the game world, and thus “in” the game, shooting the enemy, feeling “fear” and running around. However, at the same time, the players experience it as a game, as something separate from ordinary life, where the actions do not mean what they normally mean.

Counter-Strike uses some simple, very well-known dynamics to get the players into the state of play. These dynamics may be simple formulas, but they make room for improvisation in every new game and for the ongoing innovation of weapons and equipment. This is probably why the game is still popular 15 years after the first version, even though the fundamental game-play has not changed much. Counter-Strike is a rare exception in the world of computer games, where most games are used up and get boring after a short while. From our perspective, the reason behind this is the game's ability to mimic one of the most basic game formulas we have. It is not only tag or hide and seek we can point to, but also "peek-a-boo", one of the first games we learn as children, and mentioned earlier by Sutton-Smith as "paradigm for play". Moreover, to mimic this is to use the same play dynamics, not necessarily the same shape or configuration.

4.6 Conclusion

Perhaps the reader has become interested in why the various play dynamics work. We are sure that they can be explained by psychology, biology, human science or similar sciences, but we are not sure this will lead anywhere in connection to design, because we do not believe there is a universal theory of fun. It is not even the case that all play is funny, and thus, play dynamics do not only invoke fun, but also other feelings which are pleasurable, such as the "fear" in Counter-Strike. Not least, a brief observation of what human beings find funny, pleasurable, joyful, engaging etc., will show that this is different from culture to culture and from individual to individual.

We believe that understanding the play dynamics at work/play in games and play equipment will allow us see how we can use play dynamics in new ways and how we can further develop the existing dynamics. In this paper, we have found some of the play dynamics that some games and plays use to get the player into the state of play. We cannot give prescriptions for the creation of products with good play dynamics yet. We can only postulate that any product that wants to create play for users has to evoke play dynamics. This also entails that we need to get a better understanding of which play dynamics work under what circumstances, and how we create these within games, toys and so on. Future research will reveal more of these dynamics and allow us to get a deeper understanding of what is at play when we play.

Chapter 5

From Play to RCT

In the past chapters we have been working towards the development of a framework for how to understand what play is and how to create play. The main point has been to understand what play does to us and as part of that, why we in the pilot studies could see the participants engage so much in playing on the tiles, and get the outcomes they did (14-22.4% performance increase in physical tests [2]).

While it can seem obvious that training improves the score of the participants, it should be noted that the interaction with the MOTO tiles are not strictly structured as training and it is not created by physiotherapists or the like. Further, it is interesting to see that these participants actually got the improvements from very little active time - with a total playing of less than two hours. We claim that the understanding of play and play dynamics presented above can give us an insight into how this works (i.e., why they get this improvements), and, maybe more importantly, it can guide us when we want to design new playware technology or play tools in general in the future.

We have also seen that in the view presented so far, play is something we engage in for the sake of the enjoyment it brings. It is voluntary and part of a special framing process or, as we have formulated it: a special state -the state of play. We have further seen that by using ANT as a framework for analysis, we can understand how and why games work on us as players, and how they can make us do certain things (say the wrong sounds, move our body etc.), because we want to participate in and progress in the game (i.e stay in the state of play). Finally, we have seen that play tools have certain built-in functions that work on the players (play dynamics) by pushing them into the state of play. If we are to sum this up, we can look at a play situation and analyze it with the new insight we have gained. In the following we will do this with the MOTO tiles, as they are the chosen playware technology for study in this thesis.

First, we will look at what a prototypical use of the MOTO tiles is, outlined below:

Four older adults (average age of 83 years old) sit on chairs around ten tiles lying on the floor. A caregiver holding a tablet explains to the participants how the tiles work by choosing a game (Color Race), where one tile lights up in red and the caregiver has to step on it. When the tile is stepped on, the red light "jumps" to another tile and the caregiver then steps on that tile. After 60 seconds, the game is finished and all the tiles light up in red, indicating that the color red "won" the game. As there is only one color (i.e. one player) in this game, this is more an indication that the round is finished.

Afterwards, it is the turn of one of the participants to try the game. An 86-year-old women stands up next to the tiles while the caregiver starts the game on the tablet. The older woman is a little insecure and the caregiver holds her hand while she steps up on the first red tile. The color jumps to another tile and the women steps to that tile. It jumps again and she looks around to find it and then steps on it. After a few times of stepping on the tiles that light up, she cannot find the tile that is lighting up. She then lifts her skirt a little and looks down between her legs at the tile behind her. "Ahh, there it is!" she says with a smile, and steps backwards on it. She starts to gather speed and is able to step on 25 tiles before the time is up and the first round finishes. The caregiver starts another round and this time the woman is more secure in the movement on the tiles, though still holding the hand of the caregiver.

Next up is a man who is 80 years old. He is using a cane and walks slowly up to the tiles. He has tried the tiles earlier and knows the game and tiles fairly well. The caregiver starts the game and the man quickly steps on the first tile that lights up and hurries over to the next. He is fast, and "catches" 35 tiles before the round is done and the caregiver starts another round. After the second round, the man sits down and states: "Whew, that was hard.".

Similar experiences are seen with the last two participants and with the rest of the rounds they play.

If we look at the above description of the use of the tiles with a group of older adults, we can see that they quickly understand the rules of the game (here, it is fairly simple: step on the red tile), but they also quickly get the feeling of enjoyment (this we can see from their smiles and their tone of voice). But what is actually happening?

Let's first look at it from the view of ANT as presented earlier and in [4]. The tiles have the inscription of being objects that light up in bright colors (such elucidation is also one of the psychological strategies that Apter pointed to [104]). The tiles are formed as puzzle pieces in the size of the foam puzzle pieces that can be bought as toys for children. This design makes them easy to assemble, but it also makes it easy to recognize them as something that we can interact with thus, we can say that the tiles "call" to be stepped on. A good example of this "calling" we experience when we display the tiles to new people. Regardless to whom we present them, we almost always experience that people cannot help themselves from stepping on the bright colors. Often this initializes the process that the color jumps near to another person, who also cannot resist stepping on the color either, and immediately we see a connection and laugh from the participants.

If we look at the inscription of the tiles and the game "color race" (let it be noted that there are many other games, but this is the one we have chosen here), we can say that the tiles are as described above are inviting to be stepped on, while the game itself utilizes this need to press the color by letting another tile light up the moment the color is pressed. This gives the effect of the color jumping from tile to tile and the player has to race after it (thus the name "color race"). That the light jumps from one to another "force" the player to act in accordance with the game rules and move his or her feet to the other tile. In the same way as described earlier in the analysis of the board game “Quackle!”, the game puts the player's body to work. Notably, it is not only the game that can affect the player, but also the context. Having the tiles placed in a social setting where others are watching and sometimes cheering on enhances the effect of this "force". We often heard the participants say that "the game is fast", though they can take all the time they want to proceed to the next tile. Of course this is not the understanding they perceive they believe that they need to get there quickly. We also observed that the players twist and turn to find out where the color has jumped to. In this way, the game and the setup of the play is making them move more than they think they are moving.

If we look at the 80-year-old man playing it is notable that he states it was hard to play, but he does not state this until he is sitting down. This is no coincidence. He simple did not realize it before he was sitting down. He was not feeling that it was hard while he was in play, when he was acting as the game prescribed him to do. Further, it clearly pushes him into the state of play, where he is not thinking about time and place and the effort he puts into it. He is simply having fun. If we look at the situation from outside, the effort of stepping on the tiles and hurrying over to the next looks very strange for outsiders, which we also experienced a few times when someone passed by and started commenting on the actions of the participants. The actions only truly make sense in a play frame.

Next we can look at the play dynamics that are being utilized in the game and the play situation. First of all, we can see that competition is a key dynamic. As was also described earlier, this is one of the most used dynamics in games. But color race also utilizes a dynamic of physical movement, which in many ways is similar to the one known from dizziness games as also described earlier. The players have to move their body around and sometimes twist and turn in order to play the game. For some participants, it was very clear how this dynamic was working on them as they started laughing and grabbing hold of the hand of the caregiver, because they felt the swirling sensation that turning around and around can give us. For the older adults in the study it did not demand much body movement before this feeling occurred, due to their sedentary life style.

Apter describes how bright light can give arousal, and while here it is not in the sense of a flashing bright light of a disco, we can see that the players are drawn to the color and stepping on it as they move around on tiles during the play. Here, we also encounter another aspect of the dynamics at use: the immediate feedback that the tiles bring stimulates further engagement in the interaction with them. This is a simple mechanism that most digital play tools have, but it is no less important. It was even more evident in situations where the tiles were misbehaving and the color did not change right away. This slowed the game down and often threatened to take the player out of the state of play, as they started complaining about where the lights were, or why the tile did not change right away. Misbehaving and not doing as prescribed by the rules can be regarded as cheating in a game, and therefore it is very much a threat against getting into and being in the state of play.

The social setting is, as mentioned, another dynamic that the tiles can utilize. This dynamic, which works on top of competition, can be used in many different ways, such as in a race between players, but also just as encouragement and cheering for one another. The whole scene of shifting between playing and observing and sitting together around the same game sets the scene for social interaction, which is also a dynamic that can push us into the state of play. This is common knowledge from dinner parties and the like, where the mere act of being together, socializing, brings us enjoyment, of course because we use play tools such as jokes, irony, stories and the like. It should be noted that it is possible to play on the tiles alone in which situation this dynamic will not be activated.

As mentioned earlier we cannot give prescriptions for the creation of play dynamics due to the fact that there are a nearly infinite number of possible dynamics. What we will do in the following is to outline a framework that can guide the analysis of play dynamics in play products and, hopefully, guide design of playware or at least encourage designers to think about the concept of dynamics. We will emphasize that the following is preliminary and primarily serves as an attempt to clarify the concept of play dynamic.

The point of departure is what we see as the core principle of play dynamics, which is that they have an effect on users that under the right conditions will evoke the state of play. It is important to stress that this perspective is highly user centered and indicates the necessity for designers to gain knowledge on what the possible users are likely to react on. Given what Apter calls "the tremendous variety of devices, stratagems and techniques, which people use to obtain the pleasure of play" [104], this is no easy task. Not only do people have numerous ways to get into the state of play, but they also have very diverse and individual ways depending on cultural background, age, gender, class, and taste etc. What works for one person does not necessarily work for another, even if they have the same social and cultural background. This points to the fact that the design of playware and other kinds of play tools is dependent on deep knowledge of users, which often demands thorough field studies of user experience. Such studies should of course be guided by theoretical knowledge of play and the play theories we have presented earlier can provide guidance here.

Theories on play and games can help us to distinguish between different kinds of games with different kinds of effects. Callois offers one way of differentiating when he classifies exiting games into four groups: competition, chance, vertigo and simulation. Although Callois does not talk about dynamics the four groups can be said to define different kinds of play dynamics, of course in a very general sense. In the examples of products, we have analyzed above, we have seen all of the four general dynamics in function. In an attempt to expand Callois' categories into a more usable instrument for analyzing playful products Costello and Edmonds [130] look to Cziksentmihalyi and Apter, who not only divide play into more categories, but also are aware of the effects of games and play tools. According to Apter it is possible to describe a set of "general psychological strategies" for obtaining the pleasure of play [104]. These strategies represent ways, which can stimulate the human body or mind to reactions that will create play. One example is according to Apter exposure to arousing stimulation as loud music or bright colors, another is facing danger, of course in a protective frame as in the example with a tiger in a cage mentioned earlier.

Apter lists seven different strategies and they have inspired game researchers to develop a framework that is relatively fine-grained as illustrated in the following figure. Costello and Edmonds [130] further develops the framework based on work done by two game researcher, Garneau and LeBlanc, and their own research. The illustration shows how the categories from Callois' original work on play and games are expanded and extended into what can be regarded as types of play dynamics (see figur 5.1).

While this framework still is general and needs to be expanded even more, it can at least guide the point of view when we are designing or analyzing products. It would be beneficial to use the framework above to develop a specific record of subcategories of play dynamics for each new product.

If we use the MOTO Tiles as an example, we can, for instance, use the

Callois	*Csikszent'*	*Apter*	*Garneau*	*LeBlanc*	**Framework**
			Power Creation	Expression	**Creation**
		Exploration			**Exploration**
	Problem Solving		Discovery Intellectual problem solving	Discovery	**Discovery**
		Challenge	Application of Skill	Challenge	**Difficulty**
Competition	Competition		Competition Advancement & Completion		**Competition**
Chance	Risk & Chance	Facing Danger	Thrill of Danger		**Danger**
			Immersion Beauty	Submission	**Captivation**
Vertigo		Arousing Stimulation	Physical Activity	Sensation	**Sensation**
					Sympathy
Simulation	Creative	Fiction & Narrative		Narrative	**Simulation**
				Fantasy	**Fantasy**
	Friendship & Relaxation		Love Social Interaction	Fellowship	**Camaraderie**
		Negativism Cognitive Synergy	Comedy		**Subversion**

Figure 5.1: Framework taken from [130].

framework to observe two important things: The first is that the tiles are utilizing more than one play dynamic, since we can find competition, difficulty, sensations, sympathy and camaraderie when the use is analyzed as we did above. The second thing is that the play dynamics can stem from both the direct product use and from the context, which the use of the tiles demonstrated. The last-mentioned is a vital part of the effect that the MOTO Tiles have on the users, since it is the source of competition, sympathy and camaraderie. A product like MOTO Tiles has an impact on the context by establishing a kind of "stage", where social interaction can take place. To set the record straight, it should be mentioned that the MOTO

Tiles and not least the game “Color Race” originally was designed as a multiplayer game, where the social part is essential.

We do not believe that it is advisable to try to design play products by taking the framework from Costello and Edmonds as point of departure, or any other framework for that matter. We believe any good product should be the result of creativity, fantasy and intuition, i.e. an idea. What we will advocate for instead is that such ideas should be viewed in the light of the categories in the framework and further developed on that basis. The reason is that such a point of view can make designers conscious to both the mechanisms of the product and, not least, to the presumption that inevitably is implied in the idea, but often as tacit assumptions.

This does not only relate to play dynamics in the product, but also to the context it is designed to be used in. For this purpose, there is a need for an expanded framework or a model that can give an overview of the employment of play dynamics. The following is an attempt to bring together the various elements we have developed in this chapter starting with context and ending with the state of play. Each line represents a passage, which the users have to cross with the help of the play product and which therefore must be considered when designing and analyzing. For example, it is necessary to establish what we called “a stage” by framing the activities, which the product puts in motion as “play”, and, in addition, which kind of play, for instance, social or nonsocial. Scripts evoke the play dynamics, and the dynamics create reactions in body and mind, which should create the state of play.

It must be admitted that the model is still general and theoretical. To develop it into an operational tool we plan to test by analyzing a number of existing play products, which have been successful on the market, in the future.

The question remains, why is this of interest in a thesis working with balance training of older adults? If play is voluntary and frivolous and, thus, uncontrollable in principle, how does it fit with a subject such as games for health, where the main focus is on getting better health for the participants? To answer this, let us return to one of the problems that exergames for older adults try to address: that they have a very sedentary lifestyle, which is one of the main reasons for fall-related incidences. Further, we saw earlier that they lacked the motivation,

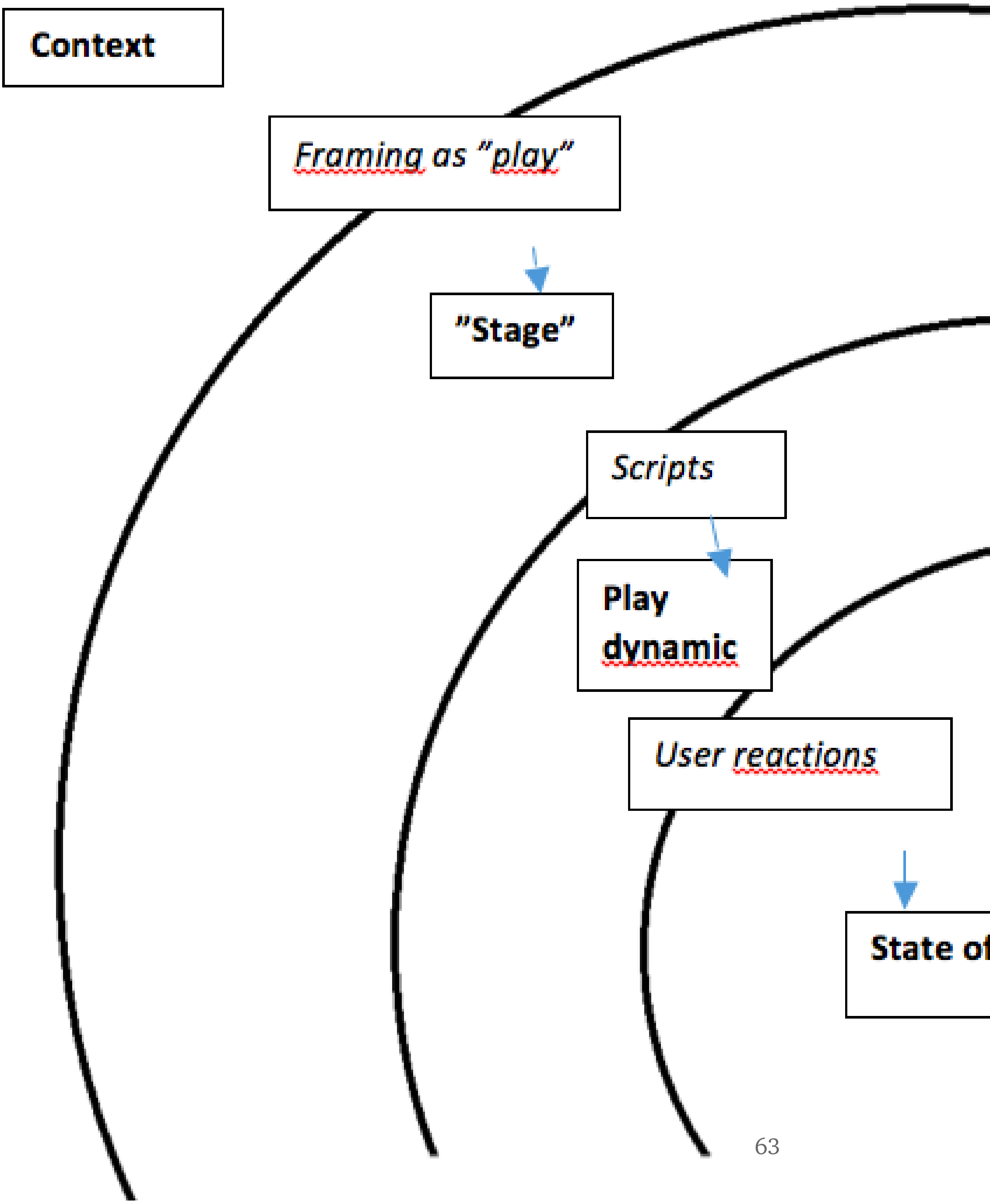

Figure 5.2: The process of play and play dynamic.

opportunities and companions to do regular training.

One of the claims that this thesis investigates is that playware technology such as the MOTO tiles can bring the a physical effect on the participants. Another claim is that play motivates them to move because they find it fun and, thus motivational.

While we have seen that play can make us do things, we still lack the ability to say that this kind of technology can have the needed and wished for effects in regard to better health. In the first chapters we saw that play can have the effect of making the participant move and thereby be active, but it remains to be investigated if playware technology such as the MOTO tiles can utilize play in a way that has effects beyond the play. As presented in chapter 2, researchers in the field of exergames are starting to do RCT with technology from the area, but most of them are of poor to average methodological quality. By doing an RCT with the MOTO tiles we hope to show it is possible to do a study with a high methodological quality and thereby find evidence that playful training gives improvements in the physiological abilities that, if lacking, have been shown to correspond with falling. We will also investigate if they find the games motivating and an acceptable form of training.

Further, we did an analysis of the MOTO tiles as a telemedicine application based on the MAST-model (Model for Assessment of Telemedicine Applications) [131]. This analysis (in Danish, but attached as appendix H for interested readers) pointed out that the next step for the MOTO tiles would be to do a full RCT.

In the following we will look at how we can gather this kind of evidence in the form of setting up an RCT and analyzing the results of this. We will investigate what is necessary to obtain a study of higher methodological quality and afterwards we will sum up on the findings of this thesis and the research done in it.

Chapter 6

RCT Studies and Studies of Balance Among the Elderly

In the last few chapters, we have looked into what play is and the contributions to the area of play research that this thesis can bring, including understanding how playware like the MOTO tiles can make us do things. In the following, we will turn to the first hypothesis and look at how we can do a study of the effect of the MOTO tiles. We will look both at what the gold standard for such investigations is, and how we can ensure that our research reaches this level of quality. Let it be noted here, that this is among the first studies done of this kind in playware, thus this section both serves to give an overview of the area, but also to allow researchers in the field of playware to understand the nature of these studies and how best to conduct them.

6.1 Why RCT?

When we are investigating if playware technology such as the MOTO tiles are effective, doing a Randomized Controlled Trial (RCT) is considered the highest form of evidence [132, 133, 134]. An RCT is a trial where the participants are randomly assigned to either intervention or control. In most interventions there are only two groups, one intervention and one control group, but some have several different forms of interventions. When investigating if an intervention is better than the current forms of intervention, RCTs are the most recognized way to gather evidence of effect.

In the following, we will look at RCTs with a brief overview plus the history behind them, and the best practices of doing and reporting on RCTs. The following serves both to give an introduction on how to create a protocol for an RCT and how to report the findings of the RCT. It further serves as a basis to better understand the protocol (see paper F and the complete protocol in paper G) for the RCT trial done as part of this PhD project, and to understand the structure and elements included in the presentations of outcome from the trial as are presented in the next chapter (Chapter 7).

When we want to investigate if playful training such as the one done on the MOTO tiles, is effective, then we need to investigate the effect of using the tiles. In the pilot study [2], we found that there was a significant increase in the tests performed after the intervention.

In the world of medicine, it has long been established as best practice to investigate how and if medicine is effective by doing RCTs.

Research has suggested that non-randomized trials have a tendency to overestimate or underestimate the effects of the intervention [133, 134].

As an example of this, surgeons in the 1970s and 1980s did surgeries that they believed prevented strokes by doing extracranial to intracranial bypass. Comparisons were made of nonrandomized groups, who for different reasons did or did not have surgery, and these studies gave more support for this belief. However, in a surprise for the surgeons in 1987, Haynes et al. [135] showed in an RCT that the only effect of the surgery was to increase adverse effects in the patients receiving surgery.

Stories like that give further backup to RCTs as the highest form of evidence. Another advantage of doing an RCT to investigate effects, is the quality of these studies, associated with its inherent internal validity, because potential confounding variables can be controlled for, thereby potentially providing strong evidence for cause-and-effect relationships [136]. It is recognized that RCTs are not always suitable for ethical or technical reasons, but the potential important information derived from RCT studies is a compelling argument to do them when possible [137].

With this is mind, researchers have developed a hierarchy about which forms of evidence are best suited to base public health decisions on. Here RCTs are at the top, only surpassed with systematic reviews and meta-analysis of RCTs.

This hierarchy is undergoing debate, as it is not always possible or desirable to do RCTs for ethical or technical reasons, but the potential important information derived from such studies is a compelling argument to do so when possible [137].

Petticrew and Roberts [137] argued for a typology instead of a hierarchy, where they say that direct effectiveness is not the only kind of evidence that can be investigated. The subject of the study points to what kind of study is most suitable, meaning that, for e.g., implementation studies, qualitative studies can be more suitable.

6.2 History of RCT

Studies of effect have not always been done as RCTs, though some researchers believe that the first RCT's can be tracked back around 600 BC [133] However, most give credit to James Lind, who in the 17th century did one of the first studies, where he took similar sick people and assigned different interventions to them randomly.

While James Lind's study is one of the first accounted for, Sir Bradford Hill was one of the first people to really influence the RCT-methodology. He outlined some of the fundamental guidelines that are still used today. These guidelines include concurrent control and random allocation, where the participants are randomly allocated to the different intervention under study, or a control group. Further, Hill introduced the necessity of explicit eligibility criteria, so that the group under study could be clearly defined, along with objective outcomes and careful statistical analysis. Objective outcomes are necessary to make bias lower and analysis of the data needs to be examined to ensure that the learnings of the trials are as valid as possible [133].

Since Hill introduced these guidelines to the methodology of RCTs for providing evidence of effect the area has grown to include everything from sports [138], to learning [139] and even to our area -exergames [35].

6.3 Best practice of RCT

The area of RCT has become increasingly popular and the quality (or lack of quality) of RCTs is a constant debate. The quality of the RCTs is crucial for the evidence they provide. Therefore two initiatives have been established that we will dig deeper into here: Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) and Consolidated Standards of Reporting Trials (CONSORT).

6.3.1 SPIRIT – RCT Protocols

When doing an RCT, the protocol is essential for the planning, conducting, interpretation, oversight and external review of the study. The protocol should facilitate the process and secure that the level of potential bias is low. It guides the process and ensures that all members of a research team know the whole process. Further, the protocol allows for the reproduction of the results in later research.

The quality of trial protocols and protocol guidelines have varied in content and quality [140]. Because of this, an international initiative called SPIRIT was started in 2007. This initiative aimed at improving evidence-based recommendations to be presented in protocols [136, 140].

While the SPIRIT lists 33 items, this is only the minimum recommendation for items to be presented in protocols for RCTs. The SPIRIT was developed in broad consultation of 115 key stakeholders from different areas, all with strong ties to RCTs. In the following, we will go through the different parts of the SPIRIT recommendations (the following subchapters are based on [136, 140] and provide an introduction to the area of writing a protocol for an RCT).

The recommendations are divided into different areas: administrative information, introduction, methods, ethics and dissemination, and appendices.

6.3.1.1 Administrative information

The administrative information consists of a title, that should clearly identify what kind of study design is used and what population is the target, along with the intervention that is being investigated.

If the trial is going to be published in recognized journals, it is a requirement that the trial is registered in one of the official registries (e.g. clinicaltrials.gov).

Registering the trial increases the transparency, and helps to prevent unnecessary duplication of studies from occurring. Further, it can potentially help with the problem of researchers not reporting negative findings, as other potential investigators and researchers can find the information of the trial.

Keeping track of the protocol versions and any changes done is also important for the sake of transparency and to allow for replication of the trial. SPIRIT recommends that all changes be listed in the protocol.

Listing funding sources of both the financial and non-financial kinds helps to assess the feasibility of the study and any potential competing interests. Studies have shown that industry- funded trials are sensitive to bias [136].

Clearly identifying the roles and responsibilities of the different parties involved in the protocol and the trial allows for the easy identification responsible parties in case of clarifications as well as identifying any competing interests etc.

In general, the SPIRIT initiative recommends that the WHO trial registration data set [141] is included in the protocol. Including the information in the WHO trial registrations data set serves as a short summary of the trial for quick overview.

6.3.1.2 Introduction

The introduction part of the protocol includes describing the background and rationale for doing the study. In this part existing research should be reviewed and presented both to identify the background for doing the study, but also to limit the unnecessary duplication of data. Further, it should detail the justifications for doing the research, including the research questions under investigation as well as the potential benefits and harms should be presented. Here also the choice of comparators, dose, placebo control and others should be defined, and the rationale, plus any previous research, should be presented.

The objectives or hypothesis of the trial have important implications for the design and analysis, and should reflect the scientific questions defined in the protocol. The trial design is also described in the introduction. Different trial designs include parallel groups where each group gets only one treatment (intervention or interventions for multiarm trials or control) cross-over, where the groups start with one treatment and shift later cluster, where randomization is not done on the basis of individuals but as groups (e.g. treatment centers). The allocation ratio, often 1:1 (the same amount of participants in each group, while 1:2 would have double in one group compared to the other), and framework (e.g. superiority, equivalence, non-inferior, exploratory) should also be clearly defined here as well. Superiority involves investigating whether the intervention is significantly better than the control, while non-inferior is investigating if the intervention is not clinically worse than the control.

6.3.1.3 Methods

In the methods section, the main points of the intervention are described. The first point is unfolding the study setting. Describing the settings of the study provides important information about how the results can be transferred, e.g. to health providers in other countries. Also ethical considerations, regulations and infrastructure needs differ from setting to setting.

Descriptions of the participants to be included in the form of eligibility criteria are important for understanding the population under study. Inclusion criteria establishes a baseline set of standards and is used to screen potential participants and limit the study population. These can consist of general factors such as age and gender, but can also be health-related if specific health issues are under study. Exclusion criteria are used to eliminate candidates who are unable or undesirable for the study. This can be candidates that are too ill to participate or have illnesses that can have a direct effect on the object of the study. Also the safety of the participants can be addressed.

Descriptions of the intervention used for each group are important to detail in the protocol. This information should be detailed enough to allow for replication of the intervention and to allow stakeholders to thoroughly understand the extent of the intervention. The description should further include criteria for making changes to or even discontinuing of the trial in case of harm etc., strategies to improvement and procedures for monitoring adherence. Any relevant concomitant care or intervention that is allowed or prohibited should be listed.

The outcomes to be measured should be clearly defined before commencing on the trial, and it is important to detail the primary, secondary and any other outcomes in the protocol. The specific measure variables, analysis metric (e.g. change from baseline) and measuring time points should be presented. Why the outcome has been chosen (e.g., clinical relevance) is important for the understanding of undertaking the study.

Including a timeline to see the schedule for enrollment, interventions, and outcome assessments is important to understand the different phases of the study. A flow diagram is often used for the visualization.

Sample size calculation All studies need to consider the amount of participants needed to secure enough power for any effects to be significant, therefore sample size or a power analysis needs to be done. Also, strategies to achieve the needed number of participants should be considered and presented.

The sample size generally depends on the acceptable level of significance, the hoped power of the study, the expected effect size and standard deviation in the population.

The level of significance is also known as the "p-value". The p-value is the probability that the effect we detect is observed due to chance and not because of the intervention. If we accept a p-value of 0.05 we accept that in 5 out of 100 times we detect a difference even though a difference does not exist (i.e. we get a "false positive" result) [142, 143].

The power of a study is the exact opposite; the probability that we will not detect a difference when one actually exists (i.e. we get a "false negative" result). The typical power of studies is set to 80%, accepting that one in five times we will not detect that a real difference exists [142, 143].

The expected effect size is the effect of the intervention compared to the control. If we expect a 20% increase and no increase in the control (no treatment or placebo treatment in the control) then the expected effect size is 20%. On the other hand if we have a treatment that we know gives 10% increase and test against this as the control, then the expected effect size would be 20-10% = 10%. The expected effect size is estimated on the basis of previously reported or preclinical studies (e.g. pilot studies). If the effect size is large then the required sample size is less and on the other hand if the effect size is small the required sample size is large.

Finally the standard deviation is needed, as a large deviation in the data will mask the difference between the two groups by the inherent difference between them because of the variance. The smaller the deviation the smaller the required sample size and vice versa [142, 143].

Allocation and blinding For any RCT, allocation of the participants and the "blinding" of them are important steps. It should be described how this will be done. Who is responsible for, and how will, the randomization sequence be performed, who and how will the participants be allocated and who and how will blinding occur (e.g. blinding of participants, assessor, data analysists etc.).

The concrete plans for collecting, managing and analyzing the data from the study needs to be presented in the protocol. This should be done in terms of the collection of baseline and outcome data, management of the data and plans for analysis of the data. It is important to specify all statistical methods planned, including sub-groups and adjusted analysis, so it is clear before commencing on the trial what analysis will be performed.

Monitoring of harms is another important aspect. For large trials data monitoring committees are established and the plans for these should be presented.

6.3.1.4 Ethics and dissemination

Beside the main points of the intervention, the protocol needs to address how it will obtain ethical approval, how confidentiality will be secured, including who has access to the data, and plans for obtaining informed consent from the participants.

Declaring any financial or other competing interests is also important to address in the protocol along with plans for the dissemination of the results.

6.3.2 CONSORT - Reporting of findings

In this section we will look at the idea behind the CONSORT statement and the different areas it touches. As this RCT is the first done with technology developed at the Center for Playware, part of the research has been to investigate how best to do an RCT of playware technology. As such, this section will be fairly detailed, as it is also intended to be used as recommendations and guidelines for future studies of playware products both for health applications and other areas.

Like the SPIRIT statement, the CONSORT statement was created to improve the RCTs done. While SPIRIT is focused on the protocol and planning of the trial, CONSORT is focused on improving the reporting of RCTs. Several reviews have documented problems in large sections of clinical trials, particularly in such areas as the reporting methods for assigning participants to groups, definition of primary end points and sample size calculations. This is the reason that the CONSORT statement was created [132].

The CONSORT statement can be applied to reports of non-pharmacological trials, but certain issues, such as the complexity of the intervention, and difficulties with blinding, present specific challenges that are not covered adequately. To deal with the special problems in non-pharmalogical trials, an extension to the CONSORT statement has been developed [144, 145].

In the following, we will look at what the CONSORT statement recommends as items to be included in the reporting of findings from RCTs (based on [132, 146] and the non-pharmalogical trials extension [144, 145]). This part is meant as an introduction to reporting the outcomes of RCTs.

6.3.2.1 Title and abstract

The abstract should contain sufficient information to provide a clear understanding of the trial and the findings. Sometimes healthcare decisions are based solely on the basis of the abstract, as the complete papers are not always accessible. Therefore, it is important that the abstract gives a concise presentation and understanding of the trial and the findings [132, 147, 148].

The abstract should include information about the trial design, methods, results and conclusions. Moreover, trial registration and funding should be included. In the methods section, it is important include information about the participants, how they are randomized, the interventions used, the objectives, outcome measures and the blinding process used. Further, the results should include the numbers of participants included in the analysis and outcome found from the trial. Any harms found doing the trial should also be presented in the abstract [132, 147, 148].

6.3.2.2 Introduction

The introduction should include the scientific background and rationale for doing the trial, e.g. exploratory or pragmatic. This should include references to existing literature and reviews that can justify the need for the new trial. Any evidence of benefits and harms should also be included here

The introduction should further include the objectives or hypotheses that the trial is designed to answer and what kind of study it is.

6.3.2.3 Methods

The methods section is where the details of the intervention are described, including a description of the trial design, such as the conceptual framework (e.g. superior or non-inferior), comparative groups (e.g. parallel, factorial or cluster), and ratio of allocation (e.g. 1:1 or 1:2). Any changes to the chosen methods done after the commencement of the trial should also be described, with reasons.

The eligibility (inclusion and exclusion) criteria should be clearly stated, so that readers can easily identify the target group. The study settings should be described emphasizing any special circumstances that are relevant for the results to be transferred to other settings.

Intervention The intervention should be described with enough details to allow for the replication of the trial. Analysis of non-pharmalogical interventions have shown that only 29% of the trials had complete descriptions of the intervention [149]. To improve the quality of future research and reporting, the "Template for Intervention, Description and Replication" (TIDieR) [150] has been developed. This template includes a checklist of items that should be included in the reporting of the interventions. The same method should be followed with the reporting strategies, to ensure adherence in non-pharmalogical trials, which is important for the reproduction and transfer of the findings [145].

Both qualitative and quantitative data should be included in the description. Quantitative data could include the amount and/or duration of main components, and overall numbers such as the duration of each session. Qualitative data could include a description of the content of each session, how it is delivered (individual or group), and whether the treatment is supervised.

All trials have end points (outcomes) which are assessed. It is important to describe the clear primary and secondary outcome measures in the reporting of the findings. These outcomes should be pre-specified, and a description of who and when they were assessed needs to be included. Should the outcome change doing the course of the trial, this needs to be explicitly described and reasons for the changes given.

Sample size The sample size of an intervention should be calculated carefully in order to secure that enough participants are involved. It is likewise considered unethical to include more participants than needed for the study to show effect. This is because any intervention will expose the participants to both known and unknown risks associated with the trial. Furthermore, it can be costly to include too many participants. How the sample size was determined (e.g. previous pilot studies) should be described as well.

Randomization and blinding RCTs are considered the gold standard of interventions because of the use of randomization and blinding. The randomization eliminates selection bias and balances the groups for known and unknown confounding variables [151]. There are many types of randomization from "simple randomization" to block or stratified randomization. The simple randomization technique is the best to avoid any selection bias and can be compared to a coin toss.

Blinding or masking refers to hiding information to people involved in the trial about which intervention is assigned to the different participants. There are several forms of blinding, including participant blinding (e.g., administering a placebo treatment), outcome assessors blinding, and data analyst blinding. Blinding is done in order to avoid detection bias. Blinding and randomization are some of the methods to secure a higher methodological quality of trials, as bias is avoided or minimized in this way.

Data analysis The statistical handling of data is another important point to address in the reporting of findings. Data can be analysed in many different ways, and they will almost always give an estimate of the treatment effect. But not all analysis methods are equally appropriate. When reporting on the statistical analysis the handling should be described so that given the same data set, the results could be verified. As most RCTs seek to verify an intervention or investigate the effect, information on the estimated effect (e.g. in the form of a confidence interval) should be presented. An evaluation of statistical significance in the form of p-values should be included with the actual value rather than just thresholds. Any additional analysis other than prespecified and exploratory should also be presented, including any sensitivity analysis preformed [152].

These first parts allow the reader to judge the validity of the analysis, and how likely they will be able to obtain a similar outcome. In the following, we will look at how to report the actual results of the study.

6.3.2.4 Results

The progress of the participants shown using a flow diagram is a visual way to represent the participants at every stage of the trial. For each group the diagram should include the numbers of participants who were randomly assigned, who received intended intervention, and who were analyzed for the primary outcome. An example of a flow diagram can be seen in chapter 7, figure 7.2.

The time period of the different stages of the trial should also be presented, including recruitment, enrollment, baseline and follow-up testing. Should the trial be stopped prior to the planned end point this should be described thoroughly, including the reasons for stopping and who stopped the trial.

Results should include a table showing baseline characteristics that allow the reader to judge how relevant the findings are to specific patients.

For the results of the analysis the number of included participants should be stated, and whether they are included in the original allocated group. Some trials only do analysis on the basis of the participants actually getting all of the planned interventions (per-protocol), while others include participants in the group they were allocated to regardless if they followed the protocol or not (intention-to-treat).

The effect size and its precision on both primary and secondary outcome is important to understand the results of the intervention. Often a 95% confidence interval is used to present the precision. The contrasts between groups also help understand how effective the interventions are. All planned primary and secondary results should be reported, and p-values can be included to provide information about which effects are statistically significant. Presenting confidence intervals can be valuable in results that are not statistically significant, because they can indicate that an important clinical difference can exist.

Other analysis done, such as sensitivity, subgroup and adjusted analysis, should be reported clearly distinguishing the pre-specific from the exploratory. Finally any important harms or unintended effects for any of the allocated interventions should be included.

6.3.2.5 Dropouts and missing data

A big issue in the analysis of data is missing data. Data can be missing because e.g. participants dropped out, were excluded, if they did not attend follow-up, no data were recorded for certain outcomes, etc.

Ideally no data should be missing from a trial, but in practice almost all trials experience some kind of missing data. As such trials should plan actions to minimize the amount of missing data as missing data inserts bias into the trial.

There are two main areas that missing data are affecting. First of all the power of the study is affected by missing data. As presented earlier, the power analysis is done in order to calculate the amount of participants needed to get a statistically significant result. If the cases with missing data is simply excluded the amount of participants decrease and the statistical power goes down. Further, according to [153] non-completers might be more likely to have extreme values and this can lead to underestimation of the variability and artificially narrowing the confidence interval for the treatment effect [153].

Second, missing data introduces bias into the study. This relates to the randomness of the missing data. Missing data can be divided into different kinds: missing at random (MAR), with a sub-set of missing completely at random (MCAR), and missing not at random (MNAR) [154].

MAR are cases where dropout depend on responses at any or all occasions prior to dropout and this assumption implies that the behavior of the post dropout observations can be predicted, and that response therefore can be estimated without bias using exclusively the observed data. MCAR is the case where the missing data is independent at every occasion and it is not dependent on the observed or unobserved measurement (e.g. a patient moving away for no reasons not related to the trial). Schafer et al. [154] calls these the ignorable missing data. MNAR on the other hand is called the informative case, where the missing data depends on unobserved measurements [154, 153].

While it would be possible to ignore missing data of the MCAR and to some extent the MAR kind without introducing bias, it is not possible to know if the assumption that the missing data is MCAR or MAR is correct.

To accommodate the problem of missing data different types of handling have been presented. Before we look at these we will take a look at the notion of dropouts.

Little et al. [155] points out that there is fundamental difference between dropouts and discontinuation of treatment. When participants discontinue the treatment an effort should be done to keep consent for collection of data and outcome including follow-up. As such, the discontinuing of treatment is not necessarily to be understood as dropouts [155]. Besides missing data (e.g. participants dropping out or not attending follow-up etc.) following the protocol (i.e. receiving all of the planned intervention) is often a problem. For different reasons the participants do not always receive the intervention they were assigned or they only receive parts of the intervention.

As presented above data analysis have to take different problems of interventions into account. As such different strategies exist to handle the data. To accommodate the challenge of not following the protocol it is possible to do per-protocol analysis, where only the participants following the protocol are included. To handle missing data it is possible to do complete case analysis, where only cases with complete data are included. However, both of these strategies are problematic. In the case of the per-protocol analysis the assumption is based on the scenario that all participants receive the treatment with full compliance following the treatment schedule, which is not a realistic real world scenario and thus might overestimate the actual effect in real use [153]. In the case of complete case analysis the assumption is that any missing data or dropouts can be ignored and will have no effect on the outcome of the trial. This, as presented earlier with the notion of MAR, is problematic.

Finally another solution, which is the most recognized strategy, is to do a so-called intention-to-treat analysis (ITT). In ITT all participants are analyzed according to how they were allocated (e.g. intervention or control). Further for missing data imputation of data into the data set is used. Several different methods exist for imputation of data. Imputation can be of simple (or single) imputation of multiple/mixed models imputation. Simple imputation is in the form of taking e.g. last observation carried forward (LOCF), while multiple imputation takes several different imputations (a variety of different approaches to multiple imputation exist. See e.g. [153, 154, 156]). The critique of LOCF is that it assumes no effect of the intervention, which is almost never the case. While other methods try to accommodate for this (e.g. imputation of worst case scores for missing data, multiple imputation etc.) they all introduce different kinds of bias.

Based on the above it should be noted that all of the methods presented have problems in form of assuming different states for the missing data.

6.3.2.6 Discussion

The discussion should include a brief recap of the key findings and show a consideration of possible mechanisms. It should further compare the findings of the study with relevant findings from other published studies (e.g. systematical reviews). The discussion of limitations of the study is important, along with a brief section that summarises the clinical and research implications of the work.

6.3.2.7 Other information

Funding sources and other support should be clearly presented, including the role of the founders. The founders' role varies greatly from trial to trial, but it is important information for the reader to understand how and to what extent the founders have been involved in the different steps of the trial.

Making the full protocol easily accessible to readers (e.g. online) will help interested parties to re-produce the trial and also to see how the trial can be transferred to their specific settings.

For studies of technology used for fall prevention, the "fall repository for the design of smart and self-adaptive environments prolonging independent living" (FARSEEING) taxonomy is developed. Using this taxonomy allows for easier replication, consistency in reporting and in systematic reviews [157]. Taxonomies like these are encouraged to be used in the reporting of findings.

Registering the trial in one of the official registers (e.g. ClinicalTrials.gov) before starting to enroll patients is highly encouraged, and many journals consider it a requirement that the trial has been registered prior to enrolling participants if they are to be considered for publication. Registering a trial also helps to avoid trials being included in systematic reviews and meta-analysis' papers more than once, as the trial receives an unique trial registration number that should then be included in the reporting. Further, registration of trials protects against the problem of the non-publication of negative or inconclusive results. Non-publication of negative or inconclusive trials is a problem, because it skews systematic reviews and meta analysis in favour of the positive findings. The same problem goes for the selective reporting of trial results.

Based on the presentations of the best practice of RCTs, we will now turn to the RCT done with the MOTO tiles. This RCT is conducted on the protocol developed based on the presentations in this chapter. Paper F presents the main points of the protocol, while the complete protocol can be found in the appendix called Paper G.

6.4 Qualitative methods

To gather the qualitative data from the intervention (both the pilots and the RCT) a triangulation of data collection were used [158].

The triangulation of methods consisted of participant observations, unstructured interviews and to some extent semi-structured interviews based primarily on the work of Uwe Flick and Steinar Kvale [158, 159, 160]. The theoretical founding of the qualitative research done in this thesis is primarily based on grounded theory developed by Strauss and Glaser [161], where the main point is that the theory is constructed based on the data. While grounded theory has many aspects and is thoroughly discussed among scholars, we are here using it as the basis for how we collect and analyze the data. For a deeper presentation of the theory we will point to both Strauss and Glaser [161], but also Flick [158] who among many others have made a very clear and understandable presentation of this area. Instead we will briefly look at the methods used.

The first method used in the collection of qualitative data is observations both of a participatory kind and with the use of videos, which are often used in anthropological and ethnological research. These techniques are used to gather an understanding of the experiences and life-world of the participants. Participation in the events that the subjects under study are performing can be problematic, as it can alter situations and behavior. At the same time it is also one of the best ways to get a profound understanding of the events taking place. As such it is important for the researcher to take his or her presence into account when forming the field notes [158, 162].

Field notes are the best way to catch the data from participants observations, while transcription is possible from video data, but also transcription is not without problems (see e.g. [162] for a discussion of problems associated with transcription). The method for analysis of the data will be presented below.

While observations give insights into the objects under study, they can rarely stand alone, and are almost always used in combination with interviews of different kinds. One of the interview methods use here are the "unstructured interviews" [158, 162]. Unstructured interviews are often used in combination with collection of observational data, because they allow for the events to unfold and the research to both observe and ask questions about the events going on [162]. Unstructured interviews are never truly unstructured, but can take form of a guided conversation. The researcher is using the interview to gather information about the observed behavior (e.g. what makes the participant smile, laugh and so on) [158, 162].

As is the case with observations the outcome of unstructured interviews are predominately field notes. Sometimes these notes are done after the event, but certain events allow for them to be done while the events unfold.

Finally we have used semi-structured interviews. While unstructured interviews often are done in the midst of the events, semi-structured interviews are often scheduled beforehand and designated outside of everyday events [158, 162]. Semi-structured interviews are based on open-ended questions and the overall structure (in the form of an interview guide) is primarily in place to ensure that interview gets around the primary areas that the researcher is interested in exploring. The semi-structure allows for other questions and areas to emerge and be explored during the interview [158, 162].

6.4.1 Coding of data

As described above the qualitative data collected have been in the form of observations (partly as participant) and unstructured and semi-structured interviews. This data was then analyzed using theoretical coding. Here we will very briefly look at what the process of theoretical coding is based on the work of Flick [158].

Flick emphasizes that the analysis of the empirical material is an important element in the construction of the researcher's final understanding of the studied field. One way to get a better view of the data is coding. Coding is the process by which the empirical data is broken down, conceptualized and put together again in a new and more orderly manner. Here we have used the process of theoretical coding; an analytical method, which consists of the following three phases: 1. Open: Here the data collected is divided into sections and these sections are then separated into items to have an overall sketch of the collected data. 2. Axial: Here the coding is refined, topics and categories are created. Any redundancy in the material is removed to get a clearer picture of what the material actually contains. Here the researcher also investigates if cause/effect relationship exists. 3. Selective: Lastly the topics and categories are further clarified so that the final data is consisting of overall topics, categories and sub-categories.

Based on the topics, categories and sub-categories the research findings can be presented.

In the next chapter, we will look at the findings of this study. Let it be noted that the chapter is structured as a separate paper, not referring directly to other parts of the thesis, as it is the intention to publish these findings. This is also the reason why there is repetition of points and explanations from above. The chapter and the presentations of the results are based on the CONSORT recommendations.

Chapter 7

Results of the Intervention - the Effect of Playful Training on the Functional Abilities of Older Adults - a Randomized Controlled Trial

7.1 Abstract

Background: With an increase in the population of older adults comes an increase in fall and fall related accidents. Exergames - digital games where the player have to be physically active to play - have showed positive results in increasing some of the underlying parameters associated with functional ability. Pilot studies of playful interaction with playware technology called MOTO tiles have shown a significant increase in these parameters.

Trial design: The trial was a randomized, controlled, assessor and data analysts blinded, parallel-group, superior trial.

Methods: The randomized, controlled, assessor and data analysts blinded, parallel-group, superior trial investigated the use of playware balance training on community-dwelling older adults 70+ years. The outcome was measured using Timed Up and Go, Chair Stand, the 6 Minute Walking Test and Line Walk in pre and post-test after 12 weeks of training two times a week with 12 minutes of active training per sesion. Sisty participants were randomized, with 30 in each group.

Results: 22 participants in each group attended post-testing, and were included in the analysis. The intervention group showed a significant increase in performance in the Chair Stand test: 2.05 times (95% CI = 0.513 to 3.58, 22% increase, p = 0.011) Timed Up and Go Change was insignificant but with an decrease in test time of -1.38 seconds (95% CI = -2.77 to 0.0207, -12% decrease, p = 0.12) and no difference was shown in the 6 Minute Walking Test. The balance test of Line Walk showed an increase of 2.23 steps (95% CI = 0.88 to 3.57, 80% increase, p = 0.0017). The intervention group had a very high adherence, and they said that the technology was both motivating and the acceptability of using it was high.

Conclusions:

Trial registration: ClinicalTrials.gov: Nr. NCT02496702, Initial Release date 7/7–2015.

Keywords: exergaming, play, functional abilities, falls prevention.

7.2 Introduction

As we get older the risk of fall accidents rises [163], and falling among older adults inside or outside the home is the most common cause of fractures and hospitalization. Falling has many human and economic costs [163, 164]. Elderly people who are very sedentary have an increased risk of falling, and within health prevention, the training of the elderly in order to prevent falls is an important issue. One third of senior citizens aged 65-80 fall at least once a year [66], and half of the population over 80 [68, 69, 70]. Of the falls, 40-60% result in injury. Most are minor injuries (30-50%), but about 5-6% of these result in fractures and up to 1% are hip fractures [71]. In Denmark, about 13,000 hospitalizations were associated with falls per year in 2005, and this is expected to rise to around 24,000 per year by 2030 citerytter2012aeldre.

One of the most common reasons for falling is a loss of functional capabilities due to inactivity, and it has been well established that this loss of capabilities can be effectively reduced by physical activity [165, 67]. Research has also shown that the barriers to elderly people being physically active include poor health, fear of injury or a lack of motivation, opportunities or companionship [73, 74].

A recent Cochrane review on "Interventions for preventing falls in older people living in the community (Review)" [66] found that 159 RCTs aimed at preventing falls among adults 60+. The 159 trials had a total of 79,193 participants, and 59 of these trials (13,264 randomized participants) tested the effect of exercise on falls [66].

While prevention of falling is a well- researched area, with indications that exercise can significantly reduce the rate of falls and risk of falling [66], the outcomes of single category programmes lack evidence. Only Tai Chi has been shown to be effective [66].

Likewise, little research of this kind has been performed in the area of exergames as a tool to perform such exercises [35, 80].

A review and meta-analysis of exergames for older adults found 18 studies [80]. An earlier review done at the point of planning this intervention found seven studies [35]. The reviews conclude that exergames have an overall positive effect on improving balance and mobility, but they also point to the need for more studies with a higher degree of methodological quality (less risk of bias) [35, 80].

The goal of this project is to investigate and validate the use of one type of exergaming training tool, MOTO tiles, to prevent the loss of function and abilities and to decrease the chance of falls among elderly people. The project will compare training with the MOTO tiles to usual care in the field, with the aim of investigating whether the training will result in improved physical abilities compared with the usual care.

A pilot study of the use of MOTO tiles in a municipality, with no control group, was conducted in 2012. This initial pilot study showed that the use of playware [29] technology for training and play could provide statistically significant progress in physical abilities [2]. The pilot study had 16 participants and showed significant improvement in the balance (Line walk – LW) (65%), endurance (6 minute walking test - 6MWT) (26%), strength in the lower body (chair stand - CS) (20%) and dynamic balance and agility (Timed Up and Go - TUG) (18%) after just ten training times of 12-15 minutes per session [2]. In addition to the physical benefits, it was highlighted in subsequent interviews that it was fun to work out on the tiles, and 80% of the participants wanted to continue with this kind of playful training [7].

The indications from this pilot study and a MAST [131] investigation of the MOTO tiles indicated the need for an RCT study to validate both the technology and play as a motivation for exercise among elderly people, to help prevent loss of functionality and falls.

The MOTO tiles are a distributed system consisting of digital tiles that are able to sense pressure and light up in a rainbow of different colors. The tiles are designed as puzzle pieces and can be assembled and disassembled in a matter of minutes.

The tiles detect pressure through the pressure sensor, and the many different colors the tiles can light up inmeans that a variety of different games have been created where the player have to move around and step on the different tiles [18, 30].

7.3 Methods/Design

The description of the intervention is reported following the Consolidated Standards of Reporting Trials (CONSORT) statement [132] and the Template for Intervention Description and Replication (TIDieR) checklist [150].

7.3.1 Participants and recruitment

Community-dwelling older adults were recruited to the intervention through cooperation with two elderly day-centers in Gentofte municipality in Denmark. Elderly day-centers in Denmark are activity centers older adults can come to, in order to socialize and participate in different activities with other older adults. These centers offer daily gymnastics, creative workshops, and sometimes, out of the house activities (visits, walks and so on). The two centers covered the different areas of the municipality.

Inclusion criteria for the intervention were community-dwelling men and women aged 70 and above. As the project is a preventive study, there were no special requirements to the participants other than the above.

Exclusion criteria were: a previous diagnosis of strong dementia or a cognitive decline that prevents the understanding of simple instructions or guidelines; a previous stroke with a severe neurological impairment, such as loss of strength, and perceptual or language limitations; severe visual deficiency; inability to maintain a standing position, even with the use of a walking aid or other device; participation in rehabilitative training.

7.3.1.1 Ethical approval, randomization and blinding

The Ethics Committee of the Capital Region of Denmark approved the study (record number: H-1500670), and all participants provided written informed consent. The study is registered at ClinicalTrials.gov (Nr. NCT02496702, Initial Release date 7/7–2015).

Potential participants were interviewed either by the primary investigator or student assistants at the Center for Playware, and assessed for inclusion and exclusion criteria. After interview, the primary investigator enrolled participants. After pre-testing, the participants were randomized and allocated to either the control or intervention group (ratio 1:1) by an individual who was not involved in any of the other parts of the study. The randomization sequence was created using the online platform www.randomization.com (seed 10404). Allocation was done after pre-testing, as some potential participants dropped out of the study just before starting.

The pre- and post-tests were done by an external physiotherapist blinded to the participants' group allocations. The blinding was done by using participation numbers and pre- and post-data was obtained on different data-sheets. Participants, supervisors and care givers were not blinded.

7.3.2 Study settings

The intervention was performed and outcomes collected at the two day-centers for elderly where the participants were recruited. Most of the participants were transported to the day-center for participation in the training and participation in other social and physical activities. A few participants were able to transport them selves to the day-center.

In Denmark, care for the elderly by the municipalities consists of many different services. Care is given in form of nursing homes, day centers and care at private homes, depending on the elderly and their abilities. The care is granted by the municipalities, and there is an ongoing negotiation over the amount of money for elderly care and other services provided by the municipalities.

Activities for the elderly consist of volunteer activities such as gymnastics (local teams often with public support), day-centers where the elderly are screened and assigned to a certain center, or rehabilitation, normally after operations or hospitalization. In the pilot study, elderly people at a day-center participated in exercising with Playware technology [2].

7.3.3 Objectives

The research hypothesis for this trial was that playful training here in the form of the MOTO tiles, would make participants perform better on the follow-up tests (6-Minute Walk Test (6MWT), the 8-foot Timed Up & Go Test (TUG), and the Chair-Stand Test (CS)) from the Senior Fitness Test [12], than participants receiving usual care. Further, it was expected that the participants would also perform better on a balancing test Line Walk (LW), have a very high degree of adherence (participation in +90% of the training), and express that MOTO tiles were motivational for the training and also that the MOTO tiles have a high acceptability (ie. they want to continue training with the tiles).

7.3.4 Trial design

The study was a single blinded (outcome assessor), parallel group, balanced (ratio 1:1) randomized controlled trial conducted in Denmark. This study investigated the use of one form of exergames called MOTO tiles, and how this compared to the usual care of elderly people aged 70+. The intervention group trained on the MOTO tiles and the control group received the usual care that was provided to non-patient elderly, which at the time of intervention was no additional treatment, other than recommendations and offers of short gymnastics classes.

To allow the future synthesis of evidence or study replication, the results include the reporting of domains and categories described in the FARSEEING taxonomy [157].

7.3.5 Intervention

The MOTO tiles were used for the intervention as balance training. The MOTO tiles are tiles developed at the Center for Playware, to create playful physical interaction. The tiles have been used in areas such as children's play and rehabilitation [166, 18]. Pilot studies have shown that they can be used for the balance training of older adults [2].

The tiles are shaped as puzzlepieces, which makes it easy to set them up and put them away after use. In the intervention, the tiles were setup in a row of 2x5 tiles. Each tile has eight RGB lightemitting diodes (LED) which are mounted with equal spacing in between each other, so they can light up in a circle (see figure), and pressure sensors installed to detect when they are pressed. The tiles communicate with a tablet, and this allows for a variety of different games that challenge the players in different ways.

For the intervention, three different games were chosen; Color Race, Final Count Down and Reach. Color Race is a game where the LEDs one of the tiles light up in red. The players then have to press this tile and another will light up, making the player move to press this next one, and so on, until the time is up. Final Count Down is a game where all the LEDs in all tiles light up in purple, and the game counts down by turning of one LED at the time. When a player presses a tile, it will start over by lighting all the LEDs up again. If a tile turns off all its LEDs before it is pressed, the player loses the game and all the tiles light up in red. The last game, Reach, is played on a platform of 2x3 tiles. Here, the player starts by stepping on the two tiles closest to them. One is then green and the other blue. The player needs to have a foot on each of the colors. One of the last four tiles will then light up in either green or blue, and the player needs to step on the tile with the foot that is standing on this color, and then step back to the original tile the foot was on.

The intervention group trained using the MOTO tiles two times a week for twelve weeks. In total, 24 training sessions for each participant were planned. Because of public holidays and transportation problems, an average of two sessions for each participant were canceled.

The training sessions were done in the form of groups of 2-5 participants per set of tiles, with 1-2 sets of tiles at a time. As more sets could be used, it was possible to have groups of more people, but the different tiles could not be close to each other (they had to be 5-10 meters apart). The training consisted of two minutes of training on the tiles and then resting, while the other 1-4 participants trained (2-8 minutes of break). Then the participants trained again for two minutes, until each participant had received a total of 12 minutes of training. The sessions lasted for 30-75 minutes depending on the number of participants (the most common was 3-4 participants). The MOTO tiles include preprogrammed games that create playful training for participants the games and tiles are described further in [2, 18].

The control group received “usual care”, which here referred to normal day activities, including activities at the day-center (social, creative and physical/gymnastic activities).

Further descriptions of the intervention can be seen in figure 7.1.

7.3.6 Outcome measures

All participants were assessed under the same conditions at baseline and within two weeks following the completion of the intervention. The intervention group also filled out a questionnaire about their participation in the intervention.

7.3.6.1 Primary outcomes

The primary outcome measures using pre- and posttests of the TUG, 6MWT and CS. The tests TUG, 6MWT, and CS are described in the Senior Fitness Tests Manual [30]. The Senior Fitness Test [30] scores fitness standards (performance cut points) that are associated with older adults’ abilities to function independently. More than 2,000 older adults have been scored, and the accuracy and consistency of the cut points have been validated as clear predictors of physical independence. The test can classify each individual into one of four levels (above average, normal range, below average, or low functioning), and can be used to assess the individual’s health risk level.

TUG is a test where the participant needs to get up from a chair, walk 8ft

1. Brief name	Efficacy of Interactive Modular Tiles training versus "usual care" on physical attributes among elder adults 70+. A randomized controlled trial.
2. Why	Falling among elder is a costly problem. Research shows that training can help prevent falls. Pilot studies of the use of Interactive Modular Tiles (IMT) show that the participants can highly increase their physical abilities (Lund and Jessen 2014).
3. What (materials)	The interventions group trained using interactive modular tiles (called MOTO tiles). The MOTO tiles include preprogrammed games that create playful training for the participants. The tiles are described in Lund and Jessen (2014). The control group received "usual care", which here referred to normal day activities, including gymnastics at the day center.
4. What (procedures)	The intervention was done in the form of groups of 2-5 participants per set of tiles, with 1-2 sets of tiles at a time. As more set could be used it was possible to make groups of more people, but the different tiles could not be close to each other (had to be 5-10 meters apart). The training consisted of 2 minutes of training on tiles and then resting while the other 2-3 participants train (4-6 minutes of break). Then the participants trained again for 2 minutes until each participant had received a total of 12 minutes of training. The control group received "usual care", which here referred to normal day activities including activities at the day-center (social, creative and physical/gymnastic activities).
5. Who provided	PhD-student, research assistant and/or trained staff with experience in handling the tiles provided the training of the intervention group.
6. How delivered	Training sessions was held twice a week and was facilitated in groups of 2-5 participants per tiles set. Training was be done in 30-75 minutes sessions, and care was taken to assure that each participant got 12 minutes of active training per session.
7. Where delivered	Training was executed at two day-centers for elderly. The location had easy access for the participants and room for both chairs (for sitting while on "break") and the tiles.
8. When and how much	The intervention was done two times a week for 12 weeks, each session lasted 30-75 minutes and each participant received 12 minutes of active training each time. Some scheduled training was cancelled due to public holidays.
9. Tailoring	All participants received the same treatment as the rest of their group (intervention or control).
10. Modifications	The system used came in a new version were some games was changed so the participants trained two minutes on each game and the training time was adjusted to 12 minutes per participant. The games did not change during the intervention, as some participants had problems learning the initial games. Because of public holidays and transportation problems about an average of two sessions for each participants were cancel.
11. How well (planned)	Training will be delivered independently in each of the training facilities. All trainers will adhere to a single training protocol to ensure standardized delivery of the training across facilities. To ensure standardization of the training the trainers will discuss the training during the trial and the project manager will continuously act as observer and provide feedback to trainers with a view to further standardizing the training. The number of times the participants is present will be recorded at each session, it will also be recorded what games and the time played for each participant.
12. How well (actual)	No other changes than described in "10. Modification".

Figure 7.1: TIDieR description of intervention.

and turn around a cone, then walk back and sit down on the chair again. The participants are asked to do this as quickly and securely as they can the time from when they get up to when they are sitting down again is measured.

The 6MWT is a test where the participants have to walk as long as they can for six minutes. Due to space issues at the test locations, the 6MWT was modified so the participants had to walk back and forth on a 10 meter long corridor. This change was done for all the participants at both baseline and the assessment after intervention.

In the CS test the participants need to stand up from a chair, without using their arms, as many times as they can in 30 seconds.

The three different tests (6MWT, TUG, and CS) from the Senior Fitness Test [30] focus on health risk prevention, such as mobility, agility, balancing, and general fitness, and are well-established for testing a variety of health parameters in the community-dwelling elderly population.

Studies have shown that the 6MWT can be used as a fall risk indicator specifically for frail elderly people [167]. Furthermore, the 6MWT not only measures aerobic fitness and mobility, but also incorporates components of leg strength, balance, reaction time, and vision.

It has been shown that the TUG reflects a combination of sensory, motor, and strength abilities [168] and can be used as a measurement of functional mobility [87].

It has also been shown that the TUG can be a tool for discriminating between future fallers and non-fallers [167]. It has been demonstrated that the TUG has similar qualities for agility and dynamic balancing and that this test is a reliable test for predicting future fallers and non-fallers from among the community-dwelling elderly population [169].

The CS measures lower body strength and endurance and it has been shown that the CS is a reliable and valid indicator of lower body strength in generally active, community-dwelling older adults [170].

7.3.7 Secondary outcomes

Secondary outcomes were a balance test Tandem Line Walk (LW) [171], adherence to training, motivation and the acceptability of the MOTO tiles for training.

The LW test is a test where the participants have to walk on a line, one foot in front of the other, without correcting their walk, stepping outside the line or similar. The number of times the foot is placed in front of the other is counted, and this is the score [171].

Adherence to the training was measured by registering the number of times the participants participated, and how much they participated, at each session. The motivation and acceptability were investigated using a 7-point Likert scale questionnaire with nine questions. Original semi-structured interviews were planned. The project manager, who also participated in the training, would have done these interviews. It was concluded that the participants would have a hard time criticizing the trial and the MOTO tiles if the questions were not anonymous, as such the questionnaire was preformed instead.

Along with the questionnaire the project manager collected qualitative data. These data were collected by participation observations and unstructured interviews with the participants during, before and after the intervention [158, 162]. The data was analyzed using theoretical coding [158]. The findings from these data is not part of this paper.

A static balance test using a Wii Balance Board was planned, but was changed and not included in initial analyses, as the proposed application for collecting the data was unavailable at time of the pre- and post-tests. An alternative collection was used (http://klab.wikidot.com/wii-proj), but the data was not available at time of the writing this publication.

7.3.8 Description of tests and modifications of tests

Primary outcomes were measured using the selected tests (TUG, 6MWT, and CS) from the "Senior Fitness Test Manual" [30]. All tests except 6MWT were performed as described in [30]. For the 6MWT, the required setup was not possible in the location, therefore a line a corridor 10 meters-long was used, and the participants walked back and forth on this line.

The secondary outcome measure LW is also called Tandem Walk or Tandem Gait. The LW tests the dynamical balance of an individual and research has shown that older adults get a significantly lower score than younger people [171]. The test was chosen as a fast way of doing an extra dynamic balance test on the participants.

Center of Pressure (COP) measures were also done, asking the participants to stand on a Wii Balance Board (WBB) [172] for 30 seconds with their eyes open, then with their eyes closed. Data of the COP were collected from the WBBd using an extension to MathLab [173]. The WBB was chosen as studies have shown it to be a valid alternative to expensive COP measurements [174]. The data were run through a custom application to calculate the maximum-minus-minimum (range) on the x- and y-scales. The COP data was included as an extra analytical tool and for future reference.

7.3.9 Sample size/power analysis

The data from the pilot study (described in Lund and Jessen [2]) was used to do a power calculation. The results showed that for a power of 80, there was a need for approx. 20 people in each group. As the population of community-dwelling elderly was expected to exhibit a high variance in functional abilities (higher than the population of the pilot study), we increased the number of participants to 30 in each group. This also allowed for drop-outs from the study, which we experienced before initializing the pilot study.

Table 7.1: Data for sample size calculation

Power	80
Significance level	0.05
Expected effect size - CS	2.05
Standard deviation - CS	2.76
Expected effect size - 6MW	65.7
Standard deviation - 6MW	54.6
Expected effect size - TUG	-2.03
Standard deviation - TUG	2.26

7.4 Statistical methods

7.4.1 Primary outcome analysis

Data was collected by and from pre- and post-tests. Data will be analyzed for statistically significant differences by first checking that there is a Gaussian distribution, and then using a paired t-test, otherwise, using the Wilcoxon Signed-Rank Test. The Wilcoxon Signed-Rank Test was selected because the population of community-dwelling elderly is expected to exhibit a high variance in functional abilities. Therefore, a normal distribution of the population's test scores cannot be assumed. The Wilcoxon Signed-Rank Test is a statistical hypothesis test suitable under such circumstances. Missing data rate was higher than expected (27% compared to 10%), and this affected the statistical analysis. The missing-data was investigated and a comparison of the group completing and the group with missing-data on the pre-test data was done. All tests showed no statistically significant difference between the groups. Further, investigations as to why data was missing revealed no reasons related to the intervention. It is thus argued that the missing-data can be considered missing-at-random (MAR). This is further commented on in the discussion as a limitation of the study.

7.4.2 Secondary outcome analysis

Data from the LW test was calculated in the same way as the primary outcomes.

Adherence was calculated both as an average of each participant and an average of all participants in total. Participants who dropped out/did not attend follow-up testing were taken out of the calculation. Further any cancelled training was deducted. This was compared to a goal of minimum 90% adherence to training.

Motivation was based on the average scores on the Likert scale and standard deviation from the participant interviews (questionnaire on motivation), as was the acceptability level.

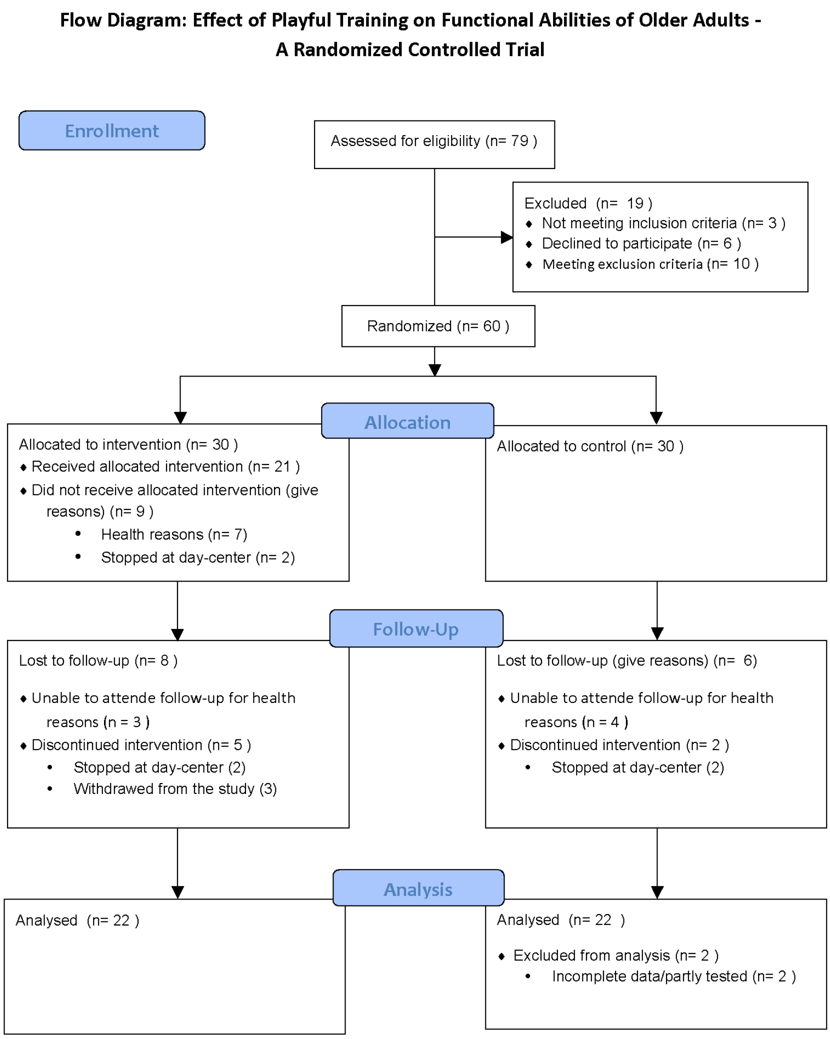

Figure 7.2: Participant flow diagram, enrollment and randomization.

7.5 Results

7.5.1 Participants and recruitment

Enrollment took place from November 2015 to the beginning of January 2016, when the sample size goal was reached. Baseline (PRE) and follow-up (POST) measures were performed in January 2016 and at the beginning of May 2016, respectively. The intervention lasted from February 2016 to April 2016. Of the 79 people screened for eligibility, 19 (24%) were ineligible or did not wish to participate. So 60 people were randomized with 30 assigned to intervention and 30 to the control group. In the intervention group, eight (26.7%) never started or dropped out of the training for health reasons, including not attending post-test for health reasons. The remaining 22 (73.3%) took part in 90.6% of the scheduled training (8% of the original planned training sessions - approximately two sessions per participant - were cancelled due to holidays and logistics problems). Of the participants in the control group, eight (26.7%) dropped out or did not attend the post-test (for health reasons). There were no differences in the baseline characteristics between the two groups.

Table 7.2: Baseline Characteristics of Study Participants - Group Mean (SD)

Characteristics	MOTO (n=30)	Control (n=30)	Total (n=60)
Female (%)	28 (93%)	25 (83%)	53 (88%)
Age (y)	83.14 (±6.69)	82.37 (±.61)	82.73 (±6.57)
BMI (kg/m2)	26.17 (±5.21)	26.16 (±4.45)	26.16 (±4.80)
CS (n)	9.23 (±4.47)	8.77 (±3.91)	9 (±4.17)
TUG (s)	12.24 (±5.13)	13.35 (±10.10)	12.80 (±7.96)
6MWT (m)	240.28 (±71.21)	237.18 (±94.77)	238.73 (±83.12)
LW (n)	2.37 (±4.36)	3.50 (±2.49)	2.93 (±3.56)

7.5.2 Primary outcomes

CS showed a statistically significant increase (more sit-to-stands in the 30 seconds) in MOTO group of 2.05 times (95% CI = 0.513 to 3.58, 22% average increase), while the control group showed an increase of 0.455 (95% CI = 0.375 to 1.28, 5% average increase) statistically insignificant. TUG showed a decrease (faster completion of test) of -1.38 second (95% CI = -2.77 to 0.0207, 22% average increase), but this figure was insignificant. The control group had a decrease of -0.0473 (95% CI = -0.837 to 0.742 ,0% average increase), also insignificant. The 6MWT remained unaffected by the intervention.

Table 7.3: Outcome of stud, Outcome = mean (95 % CI)

	Group	Outcome	% increase	p-value
CS (n)	MOTO	2.05 (0.513 to 3.58)	22%	p = 0.011
	CON	0.455 (0.375 to 1.28)	5%	p = 0.24
TUG (s)	MOTO	-1.38 (-2.77 to 0.0207)	-12%	p = 0.12
	CON	-0.047 (-0.837 to 0.742)	0%	p = 0.91
6MWT (m)	MOTO	1.07 (-15.7 to 13.6)	0%	p = 0.91
	CON	0.568 (-18.2 to 19.3)	0%	p = 0.91
LW (n)	MOTO	2.23 (0.88 to 3.57)	80%	p = 0.0017
	CON	1.09 (-0.539 to 2.72)	29%	p = 0.18

7.5.3 Secondary outcomes

Line Walk The results for the Line Walk test of the MOTO group showed a statistically significant increase (number of steps taken) of 2.23 (95% CI = 0.88 to 3.57, 80% average increase), while the control was insignificant, with an increase of 1.09 (95% CI = -0.539 to 2.72, 29% average increase).

Adherence The adherence to training was investigated by looking into the number of scheduled sessions the participants in the intervention group attended. On average, the participants attended 90.6% of the scheduled sessions. This shows that the adherence was more than the 90% expected and a little better than the average turnout in the day-centers for the same period, which was 88%. 32% of the participants had less than 90% adherence, and one of them had less than 50% participation. The primary reason for not participating was illness.

Motivation and acceptability Motivation for training on the MOTO tiles was very high 90% of participants responded that they were happy with the training, and 85% responded that they wanted to continue this training with the Moto tiles. 75% of participants self-evaluated that they had become better physically and

60% said that they could do more in their daily lives after the intervention. Most participants commented that they would like to only participate in the training once a week and not twice as in the intervention.

All the data from the questionnaire is combined in the following figure 7.3, where the 7-point Likert-scale is shortened to three points for clarity.

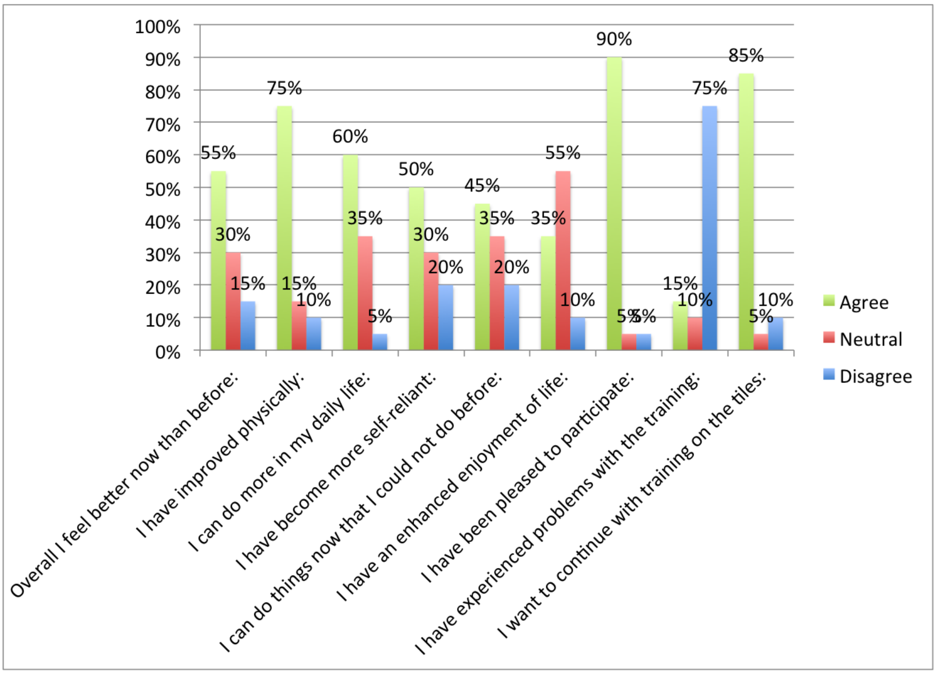

Figure 7.3: Outcome of the questioneer. A 7-point Likert-scale was used, here summed to Disagree, Neutral and Agree

7.5.4 Other analyses

Sensitivity analysis was done to assess the strength of the findings. This included the imputation of the missing data by means of "last known carried forward" methods, and the assessments of outliers. This analysis did not lead to any adjustments in the findings.

An assessment of outliers in the pre-test found that one participant scored very highly on the LW. An investigation into this case found that the test for this individual was changed from the rest of the participants. As the line to walk on was not long enough, the assessor had asked the participant to turn around and continued to count the numbers of steps. At the post-test, this was changed and an alternative longer line was established for this case. It was assessed that the pre- and post-tests of this individual were not similar and that the scores, thus, were not comparable. An alternative outcome calculation showed that without this outlier, the increase for the intervention group was 149%.

7.5.5 Adverse effects

Some participants had minor complaints of sore muscles, and one dropped out because she felt that the she had too many adverse effects in the form of sore muscles. Some comments about getting dizzy as a result of the training came from some participants, but none of the participants had these symptoms at the end of the project.

7.6 Discussion

The main findings of this study is that play on the MOTO tiles give a significant increased performance compared to control, on the leg strength test: Chair-Stand (CS) Test ($p=0.007$), and on the balancing test: Tandem Line Walk (LW) Test ($p=0.0017$). The performance increase on the balancing test was 80% (148% for the intervention group when outlier were removed) and 29% for the control (no outliers). The increase for control was insignificant ($p=0.24$).

While the improvement in the TUG was statistically insignificant ($p=0.12$ for Wilconox and $p=0.053$ for the t-test), the results show that there could be an important clinical finding, though we were not able to show it in the primary analysis. The intervention group had an increase in performance on TUG of 12% compared to 0% in the control group. There were no changes in 6MWT for either group.

Taylor et al. [175] have done meta-analysis on the trials with exergames with the tests on TUG and CS. This allows us to compare the outcome of this trial with related trials. The pooled data failed to reach significance for the TUG test (mean difference = - 2.29; 95% CI, - 5.20 to 0.64). For CS the pooled data showed a significant difference in favour of the exergames (mean difference = 3.99; 95% CI, 1.92-6.05). The mean difference for both TUG and CS are higher than found in this study, indicating that this kind of exercise might be less effective than the average of the other exergames. It should be noted that the diversity in the trial design (including intensity and intervention period) and the relative high risk of bias makes it hard to do any firm judgement.

Because the trial used a standardized protocol, the training was very rigid in the format. This could be considered a problem, since the point of the MOTO tiles are to create play, and play is characterized by being a voluntary activity that the player involves themselves in purely for the fun of it [4]. It was found that at some points the participants had to be stopped while they were actually in play, so they could have had more training than was appointed to them if they had been given the freedom to play on, rather than just following the protocol. This could also account for some of the differences that were seen from the pilot trials to the RCT in terms of outcome effect. In the pilot study, the participants were given more room to play and not asked to train for a specific number of minutes of each game, but instead a count of the total play time was taken. The pilot was done in an open and exploratory way, and it showed a higher effect on some of the outcomes compared to the RTC.

The results of the trial are in line with systematic reviews and meta-analysis work done on the field of exergames for older adults [35, 79, 77, 78, 80], which conclude that exergames can improve the balance score and mobility. It is also in line with the pilot studies done with playware exergames [1, 2].

The trial was performed to fit into the normal day activities at a day-center for older adults. The rigid protocol would be hard to follow outside of the study, but at the same time the structure allowed for less playfulness. We find that integrating the MOTO tiles into the everyday activities of the day-centers would not be problematic (it is currently done at several other places and at the day-centers involved in the study) and that a less rigid structure will be beneficial both for the outcome of balance, the functional abilities tested for, and the enjoyment of the participants.

Initial pilot testing with MOTO tiles in private homes has shown that this is feasible with 1-2 training sessions a day. Thus, trials involving home training, adherence and outcome could be a next step in the investigation of the use of MOTO tiles for older adults.

7.6.1 Limitations

The study was conducted at a day-center where participants in the study were already enrolled. The enrolled participants have a very clear over-representation of women (88%) in the study. The initial analysis was done on “complete-case”. The total number of cases lacking data was higher than anticipated. 16 participants (27%), evenly distributed with eight in the intervention group and eight in the control group, were lost to follow-up or partially tested. The initial anticipation was a maximum of 10 %. The reasons for the participants being lost to follow-up included health reasons (illness at the follow-up, not related to the intervention) and withdrawal from the trial (including withdrawing from the day-centers). An analysis of the group of missing-data on baseline data was done showing no statistical differences between this group and the rest of the participants. On the basis of the reasons for missing-data and the analysis of the group it was concluded that the data was missing-at-random (MAR).

The eligibility criteria were setup to get as broad a representation of adults 70+ as possible. Frail individuals were included, on the basis that they were able to move and stand using walking aids. Some of the cases lost to follow-up can be attributed to the inclusion of participants being too broad (e.g. they stopped attending the day-center to be put in nursing homes, suffered general illness other than balance issues). One person stopped the intervention "because this was not something for him", and one stopped "because it hurt too much in my leg".

The study does not consider any long-term effects of the intervention.

As a methodological strength, the study design was based on the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) [140] and the Consolidated Standards of Reporting Trials (CONSORT) guidelines and extension for non-pharmalogical studies [132, 144, 146].

While the trial have been setup to have a high degree of internal validity, the design of the trial also have an influence on the external validity. First of all the exclusion and inclusion criteria limits the population under investigation. As such this study have looked at 70+ community-dwelling elderly. Further, the study have looked at participants not currently in rehabilitative training, as the goal is not rehabilitation, but prevention. Second, the choice of control also has an influence on the external validity. Here we have chosen to control against usual care, which in this case could be anything from debate sessions to long walks and chair-gymnastics, which was some of the activities the elder-centers offered the attenders. The choice of non-active control can bring in attention bias, as the control gets lets attention than the intervention. In order to accommodate this we set up the trial to one offer among multiple at the elder-centers. While this does not take the active/non-active into account, it does assure that both the control and the intervention gets attention. Alternatively we could have set up non-active meetings for the control, to ensure they got attention of some kind. Here we have chosen instead to use the system already set up by going into the elder-centers. It should still be noted choosing to have a non-active control limits what we can conclude about the MOTO tiles. As such we cannot say they are significantly better than other training forms.

7.7 Conclusion

The blinded randomized controlled trial shows that playful training on the MOTO tiles increases leg strength and balance amongst community-dwelling older adults. In particular, the CS, with a 22% increase, and the LW balancing test, with a 149% performance increase, confirms the results from different pilot studies with the MOTO tiles, which also showed a very high performance increase on balancing tests (see e.g. [2]). Further, participants expressed very high happiness levels with the playful training, and consequently this results in a very high adherence to the training among the community-dwelling older adults.

7.8 Competing interests

JDJ declares no competing financial interests exist.

HHL is a director of Entertainment Robotics, which produces the modular interactive tiles.

7.9 Funding

The study was funded by the patient@home project, and equipment by Entertainment Robotics.

7.10 Authors' contributions

Jari Due Jessen (JDJ) and Henrik Hautop Lund (HHL) conceived of the project and lead the project. JDJ wrote the protocol and implemented it. HHL supervised the project strictly on the academic content as a PhD supervisor for JDJ. HHL had no decision-making authority over the project.

Falck Health/Lasse Holm-Hansen performed the physical assessments of the participants before and after the intervention.

Jonas Nyvold Pedersen did the power analysis and the statistical analyses of the data after the intervention.

Chapter 8

The Effect of Playware

As pointed out in chapter 5 it was still needed to demonstrate whether or not playware technology and the MOTO tiles had the anticipated effect on health. Thus, we wanted to evaluate if playware products could have collateral effects beyond play. As shown in chapter 7, this is indeed the case: the participants had an increase on most of the measured abilities. Though not all outcome measures gave a statistically significant increase, the results clearly showed that play on the MOTO tiles has an effect on the participant's physical health.

This is one of the main findings of this thesis and in the evaluation of the MOTO tiles. In the following we will look further into the learnings obtained from doing an RCT with the MOTO tiles, but before venturing into this we will look at some of the other data we collected from the intervention: the qualitative data. These data were obtained from observations and informal interviews with the participants both during and after the intervention. This data is not of the same standard as the data in the RCT in regards of blinding and so on, but are mainly reports of the experiences the participants had themselves. The data serve as yet another way to reach an understanding of how and why play and playware has an effect on the physical health. Also, the data shows that the MOTO tiles, and in a broader sense exergames, are a playful experience that the users find fun and engaging. Here, it is also notable that nearly all the participants wanted to continue the training after the test period.

8.1 Qualitative outcome of the intervention

When the intervention started most participants were unable to play on the MOTO tiles without help; 22 of the participants needed a hand to hold while playing. At the end of the intervention, only three people still needed a hand, and one of these people was in general not able to without the help of a walking aid because of complications in the leg from a fall a few years earlier. Overall, the participants expressed more self-confidence when playing on the tiles, which was also evident from their movements and scores in the games.

Some participants expressed problems associated with normal day walking and stated that it started to get better after participating in the intervention. For instance, one of the participants told the supervisors that she normally used a kneecap every day when walking around, because of pain in the knee, but after training on the MOTO tiles for a few weeks, she no longer needed it at all. Another expressed that she had problems with back-pains and she used a pain-relieving patch, but she stopped using these around halfway through the twelve weeks of intervention and did not use it anymore in the end.

The participants also expressed joy and increased happiness associated with the training. Some pointed out that they felt an effect outside of the training as well as e.g., one woman who said that she had much more energy and happiness in her daily life. One day she said that she had polished her silverware during the weekend, something she had not done for many years because of lack of energy. She also explained that she started walking more and was doing more things at home. Another stated that she could feel she had more energy and that her whole body was feeling better, and even felt the blood flowing better through her body. In general, she was simply feeling happier.

Getting out of bed in the morning was another topic several participants kept returning to. Normally, it was hard to get up in the morning and they often wanted to stay in bed, but when they realized they had to go and play on the MOTO tiles they had no problem getting up anymore.

Several got comments about their improvements from other participants, both while playing and in connection to their mobility in general. An example of a person, who improved so much it was positively commented by the other participants, was a woman who not only got considerably better scores in the game, but also did not use her cane when walking around on the day-center anymore. In the beginning this woman both needed her cane and a hand to hold on to in order to play on the MOTO tiles, but in the end she was able to play without any help from either cane or a hand.

There were also comments of a more negative nature. Some of these can be related to a sedentary lifestyle. For instance, many participants complained about limps, pain -and sore muscles. One did not wish to continue, because she felt it was too hard, but the rest of the participants all said that the pain was gradually getting better, and for most of them it disappeared completely before the intervention ended. We concluded that this was a matter of muscles getting activated after a long period of inactivity, because of a sedentary life style.

Another example was that a few participants complained about feeling dizzy when playing on the MOTO tiles and/or shortly after. All of these participants continued, and none of them had the problem by the end of the intervention. A very clear case of this improvement came from a woman who in the beginning of intervention had to stand still for 10-15 seconds after playing because of dizziness. In the last part of the intervention she did not have any problems, either while playing or afterwards.

In regards to the training being fun and engaging most participants claimed they really liked the MOTO tiles, but they especially found one game very monotonous (a game called "Final Count Down"), and they complained every time they had to play that game. A few of the participants had problems remembering the game rules and kept pointing out that they had never tried any of the games before, though they seemed to remember the rules of the games when playing them. For the sake of the participants who had problems learning and remembering the games, and to make sure the intervention was uniform for all supervisorsas well as for the re-constructing and transparency of the intervention, all participants played the same games and received the same amount of playing time every time.

8.2 The dilemma of play in playware

In the last section, we presented some of the qualitative improvements that were reported by the participants and those that we were able to observe during the training. In chapter 7, we found improvements in some of the physical abilities tested, and in chapter 3 and 4 we got an understanding of how the participants enter the state of play via the use of playware. From these findings, we are able to say that the MOTO tiles create play, which gives the participants the collateral effects of getting better scores and many good experiences that extent beyond the play. But what were we actually measuring? And what are the consequences of using an RCT?

Setting up an RCT is no trivial task. This was also experienced in this intervention, where it became clear that a close cooperation with Gentofte municipality was needed in order to succeed with organizing the presented trial. A great amount of time and effort was required to set up and conduct the study. The outcome should be regard in respect of this effort.

In chapter 6 we gathered a deep understanding of how to do RCTs in general, including why they are done. We investigated how to create a protocol for an RCT from the current guidelines and we created a protocol as presented in the paper F, and the complete protocol based on the SPIRIT recommendations in paper G, in order to do a study of high methodological quality that would allow us to draw sound conclusions. Based on this, we conducted an RCT of the MOTO tiles and we presented the findings following the recommended guidelines of reporting of RCTs. In this way, we have acquired the knowledge to do this kind of study in the future work on playware, although we have not yet considered the effect this has on the way playware products are being used. Reformulating the questions above, we can now ask; what is ultimately the goal of playware technology, such as the MOTO tiles? What do we wish to achieve with playware products? And how can this be connected with evaluating the effects of the playware products?

In many ways this is relevant for all playware products being developed, but returning to the MOTO tiles as the subject under investigation, we can say that we want to improve the physical abilities of the participants in order to avoid fall-related injuries. In reality, this is only a sub-goal, and actually more of a collateral effect than a main target for the product. The goal is to bring fun or engaging experiences for people of all ages (i.e. the definition of playware), and the sub-goals are to improve quality of life, gain mobility and let the participants be more self-sufficient as community-dwelling older adults. As seen, this goal is the basis for the outcome regarding improvement in physical health due to the fact that play pushes the players into a state where they exceed their normal boundaries of physical movement.

Several of these sub-goals are collateral effects of the playful interaction with the playware technology. Because play is the most important factor driving both motivation and the exceeding of the player's normal physical capabilities, it is important to ensure that the context or the framework for the training facilitates *play*. One of the possible problems with the RCT is that the measuring of collateral effects (e.g. improved balance and physical functionality) through an RCT gets in the way of the playful experiences, which should be regarded as the primary outcome of the product.

In retrospect, this was indeed a problem, as the setup of the RCT ended up being so rigid, both in regard to following the protocol and to ensure that the training was similar for all supervisors, that in fact it threatened to be and often was at the expense of playful interaction for the participants.

This is a crucial point, because as we saw in chapter 3, play is hard work, and the players only stay in the state of play if they do the work. Furthermore, we saw that as humans we seek play and want to stay in this state, therefor allowing the games to take agency and let them work both on and with us. But we also saw that play is a fragile construction that can be easily destroyed (i.e. the magic circle being broken).

So if the setup of the investigation ends up meaning that the play dynamics are not able to work on the players and they do not stay in the state of play, they will not put the needed work into the interaction. We have seen this for games where the participants refuse to take on the roles they are meant to in order for the game to work, but we also saw this when participants were unable to put the needed effort into the games on the MOTO tiles, thus, they did not enter the state of play. Further, we saw that some of the games ended up being less fun and more hard work, as with the case of the repetitive game that the participants complained about, and thus did not bring the participants into the state of play.

In general, when we are looking to gather evidence on the effect on playware products, we need to be able to adjust the settings, the participants, the supervisors and so on. This is important for future playware trials, and not necessarily something that cannot be done under the methodological constraints of an RCT. If we, e.g., work on the learning outcomes of playware products, we need to be able to allow immersion into the technology and the playful experience. In order to measure the learning outcomes, more open-ended and less guided play is required to allow the players to stay in the state of play.

If the primary goal of playware products is to create playful experiences, i.e., to push the players into the state of play, and if we can observe that the way we investigated if the MOTO tiles could "give a statistically significant increase in the underlying physical parameters when compared to usual care" (i.e. hypothesis 1) to some extent actually had an influence on whether or not the participants could get into the state of play - the next question would be if, with an RCT, we are investigating and measuring the right thing at all?

Lund [176] presents the dilemma that technologie such as playware are constantly grappling with. Playware originated partly in the natural sciences, with the traditional research methodology of performing experimental research of a positivist nature, while also being highly involved in what Lund terms the "wild, messy real-world" [176] and with play research.

When we perform a study as an RCT, we investigate the measurable outcome in an ideal case where the environment and the components, e.g. participants, can be considered fixed and not changing. With an RCT, we try to take known and unknown bias into account by randomization, but we still consider that everything else but the object under study is fixed.

But when working with playware technology, we are working with technology that should be allowed to change, to evolve, and to let the participants engage in the interaction. This interaction will be wild and messy and the outcome will change depending on the use and effort put into the interaction. We experienced this in the RCT, where it became clear that the participants putting the most effort into the interaction with the tiles were also the ones who had the most benefit from the training. An example was one participant who had problems with her vision and was often unable to really see where the color had gone to in the game of Color Race. She constantly stopped to look after it or asked for help, and she got considerably fewer points than the other participants. Further, she was one of only participants that did not increase her scores in the games during the intervention.

The point here is not that we should not do RCTs. We need evidence of effect, and, as presented several times RCTs are considered the gold standard. But we also need to be sure that we tailor the RCT and the whole plan of gathering evidence on the terms of the technology involved. We need to understand how to do a protocol of an RCT where there is room for playful interaction, but still methodological quality enough to draw sound conclusions about the product under study.

The conclusion is that we need to ensure that the elements of methodological quality i.e. biases, should be carefully understood and addressed in the forming of the protocol. That is, the randomization of participants, blinding of assessor and analyst, and the reporting of negative, positive and inconclusive outcomes should be dealt with, but the intervention should allow for a less rigid structure, where the interaction is suited to the participants. For example, not setting restraints on how much or for how long the participants interact with the playware technology, but simply just registering both the amount and the kind of interaction. Another important point could be to allow new developments that ensure the participants engage more with the technology.

In that regard, more and more customized and personalized equipment both in the health area and other areas are being seen nowadays. If we are to investigate all this personalization we need to take the above problems into consideration when we are planning, conducting and reporting on the RCTs done.

8.3 A word on the validity and what has been "proven"

In a RCT the population under study is defined by the exclusion and inclusion criteria. Here it is pointed out that we are looking at 70+ community-dwelling elderly. It is further limited to participants not currently under rehabilitative treatment.

By imposing exclusion and inclusion criteria we are limiting the external validity. This is further limited by the choice of comparator (control), where we have chosen usual-care, here in the form of non-training. On the basis of these choices we can only say that if you interact with the MOTO tiles, which we have shown can bring you into the state-of-play, you can get improvements in the underlying parameters associated with balance, and this improvement will be better than by only doing normal day activities.

Following the above limitations we have not proven that the MOTO tiles are superior to standard training supervised by a physiotherapists or the like. We have investigated if the play that the MOTO tiles pushes the players into can bring an improvement for the participants. Further, we have investigated if non-experts in a natural setting as the elderly centers can handle the MOTO tiles. A natural next step in the design right now is to investigate how this kind of playful interaction would occur in a setting where the participants can freely and by their own interest use the MOTO tiles (e.g. available at day centers or at training places without guidance).

It is worth noting that we have not tested if "play" as a standalone entity (active intervention) can bring effect, instead we have deliberately tested "play with the MOTO tiles". This opens up for a debate about the nature of play and if it would be possible to test play as an active intervention in it self. Here we will look at a setup of a test that could theoretically be used to see if the play in itself would be effective. Afterwards we will discuss the setup; whether it is at all a viable solution, and if we are indeed testing what we think we are.

Using the MOTO tiles as the basis for this setup we are designing two types of interaction. The first is the play (intervention) group. In this intervention the participants play on the MOTO tiles. We create a setup were they are moving around the tiles and engaging in the play. We have to keep track of the amount of play time and the kinds of moving around, as this is the training part, and as such not the play in itself.

Second, we have the control group. This group will do training on the MOTO tiles, but without the play. The kinds of movements and the time should be the same as the intervention group, and as such we ask them to move around on the tiles, but without the light turned on and with none of the dynamics presented in chapter 5 (e.g. competition, flashing light). We cannot remove all of these, as e.g. moving around would mean that the control should be standing still, and then we are back to a control group that is not active. There is of course different ways to make sure that they are not playing, but here we have chosen a fairly straightforward way.

As can be seen in the above section we can set up a trial, where the element we are testing for is play as we are holding other elements constant (to the extent that it is possible). While this trial could be interesting it is by no means trivial that we are testing for what we believe we are (i.e. if play is effective). Lets examine this here.

First of all we are setting up a test where both the control and the intervention (play group) are moving around. This is needed if we want to see if play moving around vs. non-play moving is actually different. But the whole test suffers from a logical problem; if we are moving around in the same manner in both groups this implies that playing should in some way improve the participants even if they where not moving (i.e. if we are keeping the movement constant). So another way to set it up where the same element is kept constant (play) would be to make none of the groups move, but have one group playing. This makes no real sense, as not moving will obviously not have an effect, unless we believe play could improve balance the same way a drug can.

This is of course not a truly fair argument, but we are trying to point out, that if we want to see if "play" is effective we need to understand that we can not test "play" as an element on its own; play is always based on something in order to work (e.g. toys, rules etc.), and play is always hard work (see e.g. []). Further, we have seen that play in its very nature is voluntary and play needs to be able to evolve if the players are to continue in the state of play. So, if we wanted to investigate if play is truly effective, then we need to make a test where the participants are able to get into the state of play and stay there as long as they want, and compare it to participants using non-play exercise (if they so choose). But then the test will be as much about adherence and motivation as it is about play as effective in bringing a better balance.

The notion of play as a state and not a touchable entity can in many ways be counter-intuitive in a engineering and medical field, but it is vital that we understand that play does nothing in itself. Play is merely a state of being (as presented earlier in chapter 5) and this state might be used to harvest different benefits, as we have done in the intervention here.

Another way of looking at testing the play with the MOTO tiles against an active control would be to consider play with the MOTO tiles as a treatment of balance, which allows us to compare that treatment with another (i.e. balance training). That would be logical, but that requires us to see play with MOTO tiles as a form of treatment in the same way as balance training. While this kind of setup is indeed possible and again could bring interesting information, the whole setup is based on an understanding that goes beyond what we can conclude after the trial done here. In this next section we will look into what we can actually conclude from the study that was carried through.

Based on the above one next step would be to do a trial where the control is doing established balance exercise. At least to the extent that we want to show that the MOTO tiles are superior (or non-inferior) to other forms of training. Such a trial would be considerably more comprehensive in the amount of people to include along with the amount of supervisors.

Showing that the MOTO tiles are superior to other forms of training have not been the goal of this thesis or the study, partly for the same reasons as it is in some ways illogical to do a study of the play element alone, but partly also because this would have required significantly more resources (economical as well as man hours) than the current study.

That said it is in the planning to investigate these issues, but as stated earlier the setup of such a trial needs to allow for a less rigid format where the participants potentially can play more than they would otherwise, and therefore the study would be more on adherence to physical activity both of playful and non-playful character. An earlier pilot-study as presented in paper E indicated that the MOTO tiles could be used in private homes. The version at the point did not allow for automatic collection of adherence, and such a study is currently in the planning phase. Yet another project is looking into how the MOTO tiles can be used un-supervised in different settings.

For the MOTO tiles the natural next step would be to investigate how they can be adjusted to the individual players, both in terms of the speed/challenges the game brings, but also in terms of the preferences and mood of the players: what it is that brings the individual into the state of play, where they will put that extra effort into the interaction needed for them to both enjoy it and want to repeat it, and also to get the collateral effect of better balance.

Chapter 9

Conclusion

In the introduction we looked at the two main hypotheses that this thesis addresses in terms of evaluating and understanding playware technology and the MOTO tiles. We investigated these hypotheses first by digging into the area of games for health, especially exergames. We found that this is a relatively new and growing area of research. Although the number of exergames as part of games for health is growing, research on the quantitative outcomes is still at an immature state. In general, the studies conducted lack methodological quality.

One of the findings of this thesis is that it is indeed possible to do studies of higher methodological quality, and as such we have done a study that secured the blinding of the assessor and the randomization of the participants, concealed allocation and reported all outcomes. The performed RCT still has some problems in terms of bias; the most dominant in this regard is the missing data, which turned out to be a bigger problem for the study than expected. Originally it was estimated that 10% would be missing, but it ended up being 26.7%. The analysis of these missing-data and the sensitivity analysis showed that this did not change the findings of the intervention, but it is an important issue to focus on in future studies.

Further, we did not find significant positive outcomes on all measures, but one primary outcome was significant (an increase of 22% in CS - Chair Stand), and one had indications that there could be an important clinical finding (decrease of 12% in TUG - Timed Up and Go), while one was unaffected (no difference in

6MWT - 6 Minutes Walking Test). These results shows that more studies are still needed and that higher power should be considered or meta-analysis on several trials combined.

The trial also showed that the participants experienced significant improvements on the balance score (Line Walk or Tandem Walk - LW) with an impressive increase of 149% if adjusting for the outlier. The reason for this outcome on the balance score is that the MOTO tiles create play, which makes the participants exceed their normal patterns of movement and limitations. This outcome is an important result for the municipality implementation project, which is targeting balancing and falls prevention amongst the community-dwelling elderly.

While the primary outcome of tje RCT is on the underlying physical parameters from the Senior Fitness Test, as this the most validated test without the ceiling effect, the scores in the LW iare also very important, not least when it comes to the integration of the MOTO tiles in the day-centers, as have been tested here.

Besides the physical measures, the participants answered a questionnaire, and here we see that the vast majority enjoyed and wanted to continue the training afterwards. Over half also reported they felt better and 75% reported that they had improved physically.

As well as the results of the RCT, we investigated how the MOTO tiles worked on the participants. We looked at how we can understand the concept of play. Here, we found that play is something we engage with only for the enjoyment it brings, because play itself is the purpose of play (according to play theoreticians, who also underlined that play is a special attitude towards the world, at "state of play").

This state is something we as humans strive for, regardless of age, but to reach the state, we have to use what we have labelled “play tools”, by which we mean material as well as immaterial phenomena such as traditional games (like the game of swirling), digital games, board games, toys, play equipment etc. The question of how play tools should be designed depends on an understanding of why they function as a means to let the users get into the state of play.

We presented a framework for an explanation building on Actor Network Theory (ANT), that in line with other phenomenon from our surroundings, games can work as actors that make us act in certain ways. This new approach was demonstrated by analyzing the network of actors in different games and swe howed how the agency is delegated to the games. The games can be said to “take over” the human player’s mind and body, and push the players to act in ways that evoke "play dynamics", which we, in the continuation of playware research, see as dynamics that bring the players into the state of play. We also saw this in how the MOTO tiles get the players to move from tile to tile in order to follow the game.

A few examples of dynamics were presented, but there is a need to further develop our understanding of the different types of dynamics and how they work together to create new dynamics and, thus, create the effects this thesis has demonstrated that physical play can produce. That kind of understanding can inform the design of playware and exergames and establish a more conscious foundation for developing new product. Hopefully this thesis has established a framework for further investigations into the field of play tools and play dynamics.

Paper A

Effect of Playful Balancing Training - A Pilot Randomized Controlled Trial

A.1 Abstract

We used the modular playware in the form of modular interactive tiles for playful training of community-dwelling elderly with balancing problem. During short-term play on the modular interactive tiles, the elderly were playing physical, interactive games that were challenging their dynamic balance, agility, endurance, and sensor-motoric reaction. A population of 12 elderly (average age: 79) with balancing problems (DGI average score: 18.7) was randomly assigned to control group or tiles training group, and tested before and after intervention. The tiles training group had statistical significant increase in balancing performance (DGI score: 21.3) after short-term playful training with the modular interactive tiles, whereas the control group remained with a score indicating balancing problems and risk of falling (DGI score: 16.6). The small pilot randomized controlled trial suggests that the playful interaction with the modular interactive tiles has a significant effect even after a very short time of play. The average total training time to obtain the statistical significant effect amounted to just 2h45m.

A.2 Introduction

Research into playware [29] and modular playware [19] puts emphasis on the design of (modular) intelligent hardware and software that creates play and playful experiences. Often, it is believed that such playware can mediate other actions, for instance actions such as social interaction and physical movement. It has been outlined how the playware may act as a play force that pushes the user into play dynamics [118]. When you are in such play dynamics, you may feel transformed from the normal state of being and feel as if forgetting about time and place. Sometimes we may feel being able to perform more or better when in play, which is interesting if such performance may have a desired side effect. Indeed, Vygotsky puts it like "Play creates a zone of proximal development in the child. In play, the child always behaves beyond his average age, above his daily behavior; in play it is as though he were a head taller than himself. As in the focus of a magnifying glass, play contains all developmental tendencies in a condensed form and is itself a major source of development." [177].

We believe that this quality of play may translate to many different groups of people. However, often accounts for the potential benefit of play e.g. on cognitive learning or physical abilities remain of a descriptive nature. Therefore, in this study, we engage in making a quantitative study of the effect of play, and we perform the study with a user group with whom play is often not attributed. In particular, to make such a study, our objective became to test for dynamic balancing of community-dwelling elderly as a result of short-term training playing with a specific playware, namely the modular interactive tiles [18].

A.3 Equipment - Modular Interactive Tiles

For the effect test of playful training, we used the modular interactive tiles as the training equipment. The modular tiles have been described before in details, e.g. [18, 178]. This is a fully distributed system made up of a number of tiles that can connect to each other to form a surface, on which people can play different games, either by themselves or by competing with each other. Each tile contains a microprocessor, battery, IR communication, an FSR sensor, and 8 coloured LEDs in a circle. The FSR sensor can sense a step or a hit on a tile, and the LEDs can shine up in different coloured patterns. This is used to create interactive games on the modular interactive tiles. Currently, there are more than 20 different games for the modular interactive tiles. The games used for the intervention are described later.

The tiles can easily be taken apart and put together to create different forms, which will demand different interaction patterns by the users when playing the games, e.g. the tiles can be changed from a 3*3 square to a horse-shoe shape in less than a minute.

Figure A.1: Left: The interior of the modular interactive tiles. Right: Assembling of a tile play field. Intervention

We prepared a small randomized controlled trial as a pilot study of dynamic balancing of elderly training with modular interactive tiles, with the objective to evaluate the effect of short-term playful training.

Twelve community-dwelling elderly people (average age: 79 (66-88)) with balancing problems were recruited from the waiting list for voluntary balancing training amongst elderly in Lyngby-Taarbaek Municipality in Copenhagen, Denmark. The population of elderly with balancing problems was randomly assigned to control group (CG) or tiles training group (TTG). The random assignment was done by lottery tickets picked by a third person blinded to the intervention.

The population from both the tiles training group and the control group was tested for dynamic balancing using the Dynamic Gait Index test before (pretest) and after (posttest) the intervention. The tests were performed by two physiotherapists from Lyngby-Taarbaek Municipality, who were both blinded to the intervention and who did not take part in the intervention.

The Dynamic Gait Index (DGI) contains 8 different tests of balancing. The

DGI was developed by Shumway-Cook and Woollacott [33] as a clinical tool to assess gait, balance and fall risk, and it is viewed as an especially sensitive task, since it evaluates not only usual steady-state walking, but also walking during more challenging tasks. The eight abilities assessed are: steady-state walking, walking while changing gait speed, walking while moving the head vertically and horizontally, walking while stepping over and around an obstacle, pivoting during walking, and stair climbing (each ability is scored 0-3). A DGI score lower than 19 points has been associated with impairment of gait and fall risk [33, 34].

DGI was collected before and after a 2-months period, during which the tiles training group performed an average of 12.5 group training sessions on the modular interactive tiles. On average, each individual performed 13 minutes of playful training on the modular interactive tiles at each of the group sessions (Fig. A.2). The control group continued their normal daily activities during the 2-months period.

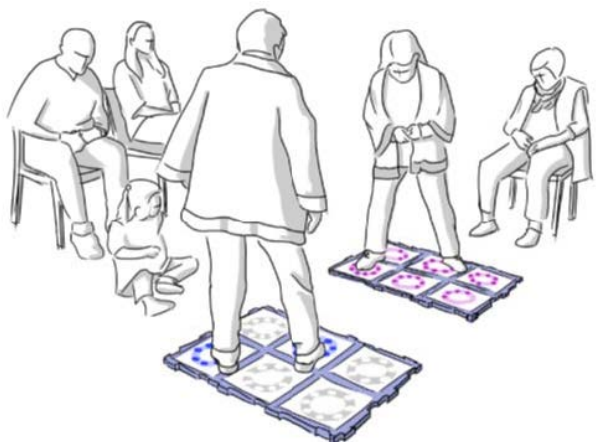

Figure A.2: The group session for playful training in the tiles training group.

The training sessions with the elderly group was planned in cooperation with physiotherapists from Lyngby-Taarbaek Municipality. In order to secure a valid result, a protocol for the intervention was designed, in which 4 games were chosen that the elderly should try out: “Color Race”, “Final Countdown”, “Island” and

"Concentration Color" (see Fig. A.3 for the protocol). "Color Race" is a game where one of the tiles will light up in red. When stepped on, the tile will go black and another will light up. The player needs to step on as many tiles as possible within 30 seconds. In "Final Countdown" all the tiles will light up in purple and each tile will start counting down by turning off one of its 8 LED's every second. When the player steps on a tile, the countdown will restart. If any of the tiles gets all its LED's turned off, the game is lost. "Island" can be compared to the children game "The Floor is Made of Lava". Here, the player needs to move from green tile to green tile or island to island, without stepping on the other tiles. Once stepped on, the tile will start counting down and the player has to go on to the next before the tile turns off. This game will automatically adjust the speed according to the player's performance. The last game "Concentration Color" is a memory game where all tiles turn white but they are hiding a colour 'underneath'. When stepped on, a tile will show the color it is "hiding". The object of the game is then to find all the matching color pairs (red, green, blue, yellow, purple, light blue).

The training group was put into two groups where each group had one hour of training. The group was placed around the tiles that to begin with were placed in a group of 3x3 tiles. This setup of the tiles was changed before playing the game "Concentration Color" where the platform was changed to a "horse shoe" formation.

The sessions was built up of small "rounds" of play, where each participant played two minutes (though only 1,5 minutes for the game Island) of each game before having a small break while the rest of the group played.

Each training session was organized like this: 2 rounds of "Color Race", 2 rounds of "Final Countdown", 2 rounds of "Island" and 1-2 rounds of "Concentration Color" depending on the time available (see Fig. A.3).

A.4 Results

The population of elderly with balancing problems was tested with the DGI, and had an average score of 18.7. In the DGI test, below 19 is viewed as the threshold for having balancing problems and risk of falls. The population was randomly assigned to control group or tiles training group. Data were analyzed for

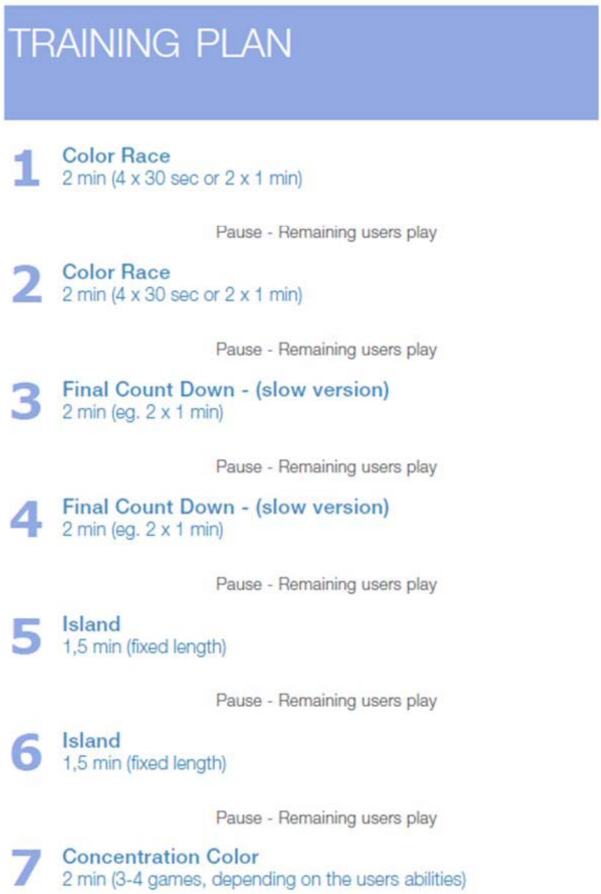

Figure A.3: The training protocol for the tiles training group.

statistical significant differences between the control group and the tiles training group, and for increase of mean score on DGI.

After the random division into the two groups, the control group and the tiles training group did not differ at baseline (DGI mean score: 18.3 vs. 19.0). After the 2-months period, there was significant difference in change of DGI score period with the control group decreasing DGI score by 9.3% and tiles training group increasing DGI score by 12.3% on average. A two way repeated measures ANOVA (Student Newman-Keuls method) resulted in no statistical significant differences at baseline. Also, there was no statistical significant difference in the control group's performance over time. There was statistical significant increase in performance of the tiles training group over time ($p<0.05$). Also, there was statistical significant difference between the control group and the tiles training group after intervention ($p<0.05$). DGI mean score after intervention was 16.6 for the control group, and 21.33 for the tiles training group, or an average decrement of 9.3% for the control group and an increase of 12.3% for the tiles training group.

The score for control group and intervention group is presented in table A.1.

Table A.1: Results of the DGI pre-test and post-test after two months of the 12.5 sessions training with modular interactive tiles.

	Pre-test	Post-test	Improvement	Significance
Control group	18.3	16.6	-9.3%	NS
Training group	19.0	21.3	12.3%	$P<0.05$

The community dwelling elderly with balancing problems seemed to be at high risk of falling if not subject to any training, whereas those who performed training increased their dynamic balancing abilities. A DGI score of <19 is associated with impairment of gait and fall risk [7, 8], so the statistical significant difference between DGI score of 16.6 of the control group and DGI score of 21.33 of the tiles training group is important.

During the sessions the elderly expressed an increase in their abilities and endurance in normal day activities. At the posttest one participant expressed that others had told her that they could see and feel an increase in her general movements, endurance and balance.

A.5 Discussion and Conclusion

Despite the limited sample set, the trend of the pilot study is clear: there is statistical significant effect from short-term playful training with the modular interactive tiles. The community dwelling elderly with balancing problems seemed to be at high risk of falling if not subject to any training, whereas those who performed training increased their dynamic balancing abilities. A DGI score of <19 is known to signify risk of falling, so the significant difference between DGI score of 16.6 of CG and DGI score of 21.33 of TTG is important, as it indicates that it may be possible to ensure that such a test population may reduce risk of falling by training on the modular interactive tiles.

The study also shows how playful hardware (playware) can be used to create a quantifiable effect on people by using play as a motivator for engagement and training.

The study has certain, clear limitations. First and foremost, the study was performed as a pilot study with only 12 subjects. A larger randomized control trial (RCT) should be performed based upon the indications of this small pilot study. Despite such limitations, it is interesting that the effect of training with the modular interactive tiles amongst the community-dwelling elderly with balancing problems was obtained after just 13 minutes of training per session for an average of 12.5 training sessions. Hence, the average total training time to obtain this statistical significant effect amounts to just around 2h45m, which is very little training time.

A.6 Acknowledgement

The work is partly sponsored by the project Patient @ Home. The authors would like to thanks participating elderly in the intervention group and control group, therapists from Lyngby-Taarbaek Municipality, and colleagues from the Center for Playware, DTU.

Paper B

Effects of Short-Term Training of Community-Dwelling Elderly with Modular Interactive Tiles

B.1 Abstract

Objective: The objective of this study is to test for the increased mobility, agility, balancing, and general fitness of community-dwelling elderly individuals as a result of short-term training involving playing with modular interactive tiles (Entertainment Robotics, Odense, Denmark) at two community activity centers for the elderly. Three different tests from the Senior Fitness Test were used in order to test a variety of health parameters of the community-dwelling elderly, including those parameters related to fall prevention.

Materials and Methods: Eighteen community-dwelling elderly individuals (63–95 years of age; mean, 83.2 years of age) were assessed in one intervention group without the use of a control group. The intervention group performed nine group sessions (1–1.5 hours each) of playful training with the modular interactive tiles over a 12-week period in two community activity centers for the elderly. Data were collected using pre-tests and posttests of the 6-Minute Walk Test (6MWT), the 8-foot Timed Up & Go Test (TUG), and the Chair-Stand Test (CS). Data were

analyzed for statistically significant differences and increases of means.

Results: The 6MWT, TUG, and CS measurements showed statistically significant differences and increases of means between the pre-tests and post-tests with the 6MWT ($P < 0.001$) (means difference, 22.4 percent), TUG ($P < 0.001$) (means difference, 15 percent), and CS ($P < 0.002$) (means difference, 14 percent). Fifty-six percent of the elderly progressed from one health risk level to a better level, according to the three tests.

Conclusions: Statistically significant increases in scores were found across all tests, suggesting an improvement of many different health parameters for the elderly. Well-established research has shown the relationship between such test scores and fall incidents, balancing, mobility, agility, etc. This significant improvement in the health status of the elderly is obtained in as few as nine training sessions over a 12-week period of "playing" exergames with the modular interactive tiles.

B.2 Introduction

The current literature shows that exercise can have many health benefits. For instance, exercise may help prevent falls in older people [66, 179]. Physiological risk factors for falls include reduced leg strength, impaired vision, slowed reaction time, poorer peripheral sensation, and greater sway [180]. Specific exercises can be used to modify some of these risk factors. For instance, various components of aerobic fitness have been linked to increased functional ability and activities of daily living [181, 182]. Conversely, decreased functional ability and activities of daily living have been linked to falls [183].

In order to motivate people to perform exercises that have these health benefits, game platforms with physical games, also known as exergames or active videogames, have been investigated as exercise tools. One of the better-known exergames is theNintendo (Kyoto, Japan) Wii ™ system with "Wii Fit", "Wii Cardio", or "Wii Sports". In addition, other exergames have been investigated, such as "Dance Dance Revolution" (Konami Digital Entertainment, El Segundo, CA), Sony (Tokyo, Japan) PlayStation ™ 2 EyeToys ™ games, and Microsoft (Redmond, WA) Kinect™ games. These platforms are all screen-based, with videogames running on the screen and users activating the games by producing physical actions in the room in front of the screen. In the process, attention is directed toward the screen while the physical actions are being performed.

However, even if indications exist [35], further evidence of health effects from playing exergames is needed. For instance, Wollersheim et al. [184] showed that despite significant energy expenditure, there were no substantial physical effects among elderly women playing the Nintendo Wii in their study. Most quantitative effect studies have focused on energy expenditure (along with heart rate and oxygen consumption) that occurs in smaller bursts when playing the games, perhaps because of an initial interest in exergames as a potential tool for weight loss. These studies were able to demonstrate differences in energy expenditure between games (see the meta-analysis of Peng et al. [185]), but evidence of effects on the general physical condition (body weight, balancing, mobility, agility, strength, etc.) of the subjects is still needed.

Reviews of the literature initial interest in exergames as a potential tool for weight loss. These studies were able to demonstrate differences in energy expenditure between games (see the meta-analysis of Peng et al. [185]), but evidence of effects on the general physical condition (body weight, balancing, mobility, agility, strength, etc.) of the subjects is still needed. Reviews of the literature concluded that energy expenditure "while playing the Wii was not greater than brisk walking." [186], p.1173 Some studies showed limited or no effect in recognized tests of fitness, mobility, agility, balancing, etc. [81, 187], although some exceptions were found with very specific patient groups (see, e.g., Gil-Gómez et al. [188] and Saposnik et al. [189]). Indeed, Lange et al. [190] and Taylor et al. [175] outlined that more rigorous standard treatments, comparisons, and tests are needed, especially for effect studies among adult subjects, in order to evaluate the potential of exergames as a general training and therapeutic tool beyond training for obese youth (e.g., as concluded in the review by Wiemeyer and Kliem [191] of serious games for use in prevention and rehabilitation among elderly people).

In terms of fall prevention training, research has suggested that recruiters for interventions sometimes recruit subjects who have too low a risk of falling and that there is a need to target those likely to benefit the most. Barnett et al.

[192] indicated that those who are likely to benefit the most are older people with strength and balance deficits, women 80 years of age and over, and those 70 years of age and over with one or more fall risk factors. For instance, in their study with 37 group exercise sessions over a year in a community setting, they found improved balance and a reduced rate of falling among at-risk community-dwelling older people. However, the same study [192] showed no improvement in walking speed and sit-to-stand time, although Lord et al. [193, 194] found improvements in previous studies that used a more frequent program (more sessions per week) with higher dosage. Therefore, it may be interesting to study whether or not the more frequent program with a high dosage of training is a necessity in order to see improvement in balancing, walking speed, and sit-to-stand time among at risk community-dwelling older people. Hence, here, we will investigate the effect of short-term playful training with modular interactive tiles among the elderly.

These modular interactive tiles [18] are used by therapists to provide treatment for a large number of patients who receive hospital, municipality, or home care interventions, but the tiles can also be used for prevention with the elderly or for fitness with the general population. Nielsen and Lund [178] described the use of the modular interactive tiles with cardiac patients, smoker's lung (chronic obstructive pulmonary disease) patients, and stroke patients in hospitals and in the private homes of patients and the elderly and showed that therapists were using the modular aspect of the tiles for a variety of personalized training, while modulating exercises and difficulty levels. Such personalization through modulation of exercises and difficulty levels may allow the system to be used for playful training also among community-dwelling elderly with diverse levels of functional abilities, as will be tested in the present study.

B.3 Materials and Methods

The modular interactive tiles [18] (Entertainment Robotics, Odense, Denmark) are a distributed system of electronic tiles that, like building blocks, can be attached to one another to form the overall system (Fig. B.1). Each tile is self-sufficient in terms of processing power, and each one has a battery that lasts for approximately 30 hours of use. This makes the usage of the tiles very flexible because the tiles do not need a computer, a computer monitor, or an external power source.

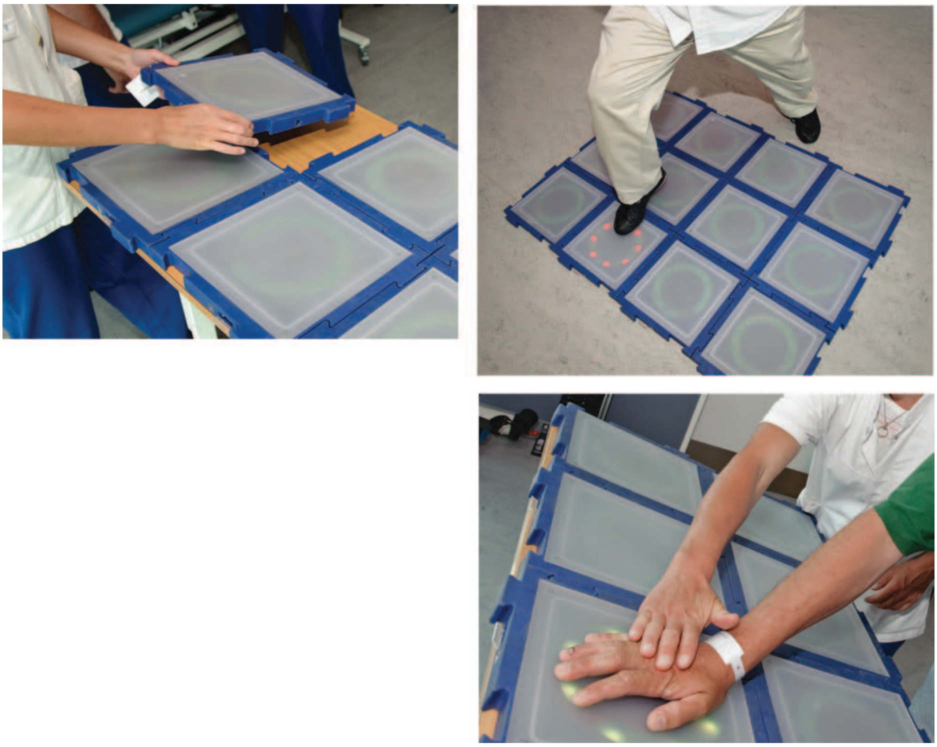

Figure B.1: The modular interactive tiles can be assembled in different configurations (top left, top right, and bottom right) for different playful exercises and levels.

When connected to one another to form a playfield, the modular tiles communicate to their neighbors through four infrared transceivers located on the sides. One tile has an XBee radio communication chip, with which it can communicate to other devices that also have an XBee chip, such as a game selector box or a personal computer that has an USB XBee dongle connected.

When playing on the tiles, the subject provides the tiles with input in the form of pressure, which is measured by a force-sensitive resistor that is located in the center of each tile. The tile can then react by turning on eight RGB lightemitting diodes that are mounted with equal spacing between each other in a circle inside the tile. Table B.1 shows the technical specifications of a modular tile.

Table B.1: Technical Specification of a Modular Interactive Tile

Description	Amount	Type
Processor	1	ATmega1280
Sensor	1	FSR
Sensor	1	Two-axis accelerometer
Effector	8	RGB color LEDs
Communication	4	IR transceivers
Communication	1	XBee radio chip
Energy	1	Li-Io polymer battery
Switch	1	On/off switch
Connector	4	Jigsaw puzzle
Size	300 x 300 x 33 mm	x
Weight	1 kg	x

IR, infrared; LED, light-emitting diode.

B.3.1 Tests

The Senior Fitness Test [30] has validated fitness standards (performance cut points) associated with having the ability to function independently among more than 2000 older adults, and these cut points' accuracy and consistency have been validated as predictors of physical independence. Each individual subject's score can be classified into one of four levels (above average, normal range, below average, or low functioning) on each of the individual tests of the Senior Fitness Test (e.g., the 6-Minute Walk Test [6MWT], the Chair-Stand Test [CS], and the Timed Up & Go Test [TUG]) and can be used to assess the individual's health risk level. Three different tests from the Senior Fitness Test [30] have been found to be useful and well established for testing a variety of health parameters related to health risk prevention, such as mobility, agility, balancing, and general fitness, in community- dwelling elderly. These tests include the 6MWT, the 8-foot TUG, and the CS.

It has been shown that the 6MWT can be used as a fall risk indicator specifically for frail elderly [167]. Furthermore, it has been shown that the 6MWT not only measures aerobic fitness and mobility, but also incorporates components of leg strength, balance, reaction time, and vision.

The TUG provides a measure of functional mobility [87] and reflects a combination of sensory, motor, and strength abilities [168]. The TUG has also been shown to be a tool for discriminating between future fallers and nonfallers [167]. The 8-foot version of TUG has been demonstrated to have similar qualities for agility and dynamic balancing and is a reliable test for predicting future fallers and nonfallers from among the community-dwelling elderly population [169].

The CS provides a measure of lower body strength and endurance, and it has been shown that the CS is a reliable and valid indicator of lower body strength in generally active, community-dwelling older adults [170].

B.3.2 Intervention

Elderly individuals at two senior community activity centers in Gentofte (Copenhagen), Denmark, were offered the opportunity to participate in playful training with the modular interactive tiles once a week for 12 weeks. The senior community activity centers are organized so that most elderly individuals are transported to the centers from their private homes once or twice a week to engage in center activities for social interaction, and the elderly participants were offered the opportunity to participate in training with the tiles as part of these center activities.

Gentofte Municipality had the study approved by the ethics committee, and the participants signed letters of informed consent to participate. Eighteen elderly individuals 63–95 years of age (mean, 83.2 years of age) participated in the training (Table B.2). Tests (CS, TUG, and 6MWT) were performed before and after the intervention (pre- and posttests, respectively). The intervention group performed nine group sessions of training with the modular interactive tiles once a week over a 12-week period (there were a few break weeks in the weekly sessions due to holiday breaks). Each session lasted 60–90 minutes, and each individual would be engaged in active play on the tiles for 10–15 minutes per group session. A research assistant would guide the group's training on the modular interactive tiles, using 10–12 tiles for each session.

During part of the session, the tiles would be split into two smaller platforms

Table B.2: Characteristics of the Intervention Group

Parameter	Value
Age (years)	83.2 (63–95)
Gender	3 males/15 females
Height (m)	1.70 (1.50–1.80)
Weight (kg)	70.1 (52.6–106.5)
BMI (kg/m2)	25.5 (18.48–31.99)

Data are average (range) values.
BMI, body mass index.

(with five or six tiles each) to allow for parallel interaction of two individuals on two different platforms. Another part of the session would occur on a larger platform of tiles, on which the participants would interact individually or in pairs on competitive games.

The games used for the training included "Color Race", "Final Countdown", "Reach", "Island Game", "Concentration Game Color", and "Simon Says" [195]. The latter two games are memory games that may potentially challenge both physical and mental skills, whereas the first four games are further challenging mobility, balancing, endurance, and reaction. Most games are designed to challenge several physical and cognitive abilities simultaneously while the individuals are playing the games.

B.3.3 Statistical analysis

Data were collected from pre- and post-tests. The average score and standard deviation were calculated, and the Wilcoxon Signed-Rank Test was used to test for statistically significant differences between the pre- and post-tests. The Wilcoxon Signed-Rank Test was selected because the population of community-dwelling elderly was expected to exhibit a high variance in functional abilities. Therefore a normal distribution of the population's test scores cannot be assumed. The Wilcoxon Signed-Rank Test is a statistical hypothesis test suitable under such circumstances.

B.4 Results

Sundhedsdoktoren, an independent third party that was not involved with the training, conducted the pre- and post-tests. The post-test was performed blinded from the pre-test results. The tests were conducted in the two senior community activity centers.

The results of the pre- and post-tests are presented in the table in figure B.2. All of the tests showed a statistically significant improvement of performance between the pre-test and post-test at levels of $P < 0.001$ or $P < 0.002$ (by Wilcoxon Signed-Rank Test). The average improvement was 14 percent on CS, 15 percent on TUG, and 22.4 percent on 6MWT. Furthermore, several subjects improved so that they transferred from one health risk level to another health risk level (according to the criterion reference points of Rikli and Jones [30]), improving at least one level (seven subjects improved their level according to the CS results, six subjects improved their level according to the TUG results, and seven subjects improved their level according to the 6MWT results). In total, 56 percent of the subjects improved their health risk level according to at least one of the tests.

Figure B.2: Results of Pre-test and Post-test of the Nine Sessions of Training with Modular Interactive Tiles

Test	*Pre-test (σ)*	*Post-test (σ)*	*Average improvement (percent)*	*Significance level*	*Level improvements*
CS	9.9 (2.6)	11.3 (3.1)	14	$P < 0.002$	7
TUG	11.0 s (6.1)	9.4 s (4.9)	15	$P < 0.001$	6
6MWT	247.6 m (82.0)	303.0 m (106.3)	22.4	$P < 0.001$	7

6MWT, 6-Minute Walk Test; CS, Chair-Stand Test; TUG, Timed Up & Go Test.

As confirmed by the quantitative data, the qualitative observations also found the subjects to be much more mobile at the post-test. For instance, it was found that three of the subjects who performed the pre-tests with the use of orthopedic aids (rollator, walker, or cane) performed the post-test without these aids or completed the post-test using the aids far less than they used them during the pre-test.

B.5 Discussion

Research has suggested that a high dose of exercise is needed to obtain significant effects on the fall rates, gait speed, and other indicators of health in the elderly population. The review and meta-analysis by Sherrington et al. [179] suggest that a high dose of exercise ($>$ 50 hours) is needed for greater relative effects of exercise on fall rates. Also, the meta-analysis of Lopopolo et al. [196] found that high-dosage intervention had a significant effect on the gait speed of community-dwelling elderly, and it found no effect for low-dosage exercise. (Gait speed is an important measure because there is evidence of correlation between gait speed and mortality [197].)

However, it is noteworthy that significant change is found, for example, in gait speed, among the elderly who performed low-dosage playful training with modular interactive tiles after merely nine sessions. In our study, there is a large increase (22.4 percent) in gait speed from 0.687 m/second in the pre-test to 0.841 m/second in the post-test, when calculated using the 6MWT. This is a large increase compared with other studies, such as the meta-analysis by Lopopolo et al. [196] of the effect of therapeutic exercise on gait speed in community-dwelling elderly. This occurs despite the fact that their meta-analysis suggested that a high dosage is necessary to obtain greater improvement. The relatively high levels of improvement in our study may be due to the fact that the elderly individuals in our study are somewhat frail, with a pre-test gait speed of 0.687 m/second, so the nine sessions of training with the modular interactive tiles may be sufficient to invoke change in muscle force-production and gait speed.

The result of low-dosage playful training on modular interactive tiles shows that the subjects improved on all three tests, and hence they improved on a large variety of physiological abilities. These abilities may include aerobic fitness, mobility, reaction time, balancing, endurance, and strength. It is interesting that this kind of playful training on the modular interactive tiles can lead to such a general improvement of functional abilities because other training methods often improve the subjects' abilities only partly.

One such method is the combined stretching, balance, and strengthening exercises method of DiBrezzo et al. [198], presented in a study that in many of the set-up parameters is comparable to the study that we present here with the modular interactive tiles. The study by DiBrezzo et al. [198] was performed over a period of time that was similar to our study (10 weeks), with a similar population (16 communitydwelling elderly individuals 60–92 years of age [average, 74.9 years of age]), in similar settings (two local senior community centers), and with similar evaluation procedures (pre- and post-test using the Senior Fitness Test, including the [8-foot] TUG, CS, and 6MWT). However, over the 10-week period, the participants performed 30 sessions (1 hour per session) of stretching, balance, and strengthening exercises in the study by DiBrezzo et al. [198] After the 30 sessions, they found statistically significant improvements on CS ($P < 0.01$) and TUG ($P < 0.001$) but no significant improvement on the 6MWT.

Our study was different than the study by DiBrezzo et al. [198] in that we included slightly older subjects (average age, 83.2 versus 74.9 years) who performed much fewer training sessions (9 versus 30 training sessions) and obtained statistically significant improvements on all three tests: CS ($P < 0.002$ versus $P < 0.01$), TUG ($P < 0.001$ versus $P < 0.001$), and 6MWT ($P < 0.001$ versus difference not significant).

It is also interesting to compare the results received in this research with the potential results of other exergames and to try to analyze why the training with the modular interactive tiles appeared to be effective for the present short-term intervention. This information can be helpful in order to understand how to create effective exergaming and training. In comparison with the use of the "Wii Fit", the study with the modular interactive tiles shows a noteworthy difference in the subjects' performance on the standard tests. Franco et al. [81] obtained no significant effect on standardized balance tests (Berg and Tinetti) when community-dwelling elderly (average age, 78.3 years) individuals were exercising with the Nintendo "Wii Fit", and Nitz et al. [187] showed in their study with adult subjects (age, 30–58 years) using a "Wii Fit" for 20 sessions that there were no improvements in the performances on the 6MWT and TUG. On the other hand, the present study with subjects using the modular interactive tiles for nine sessions showed a statistically significant performance improvement on the 6MWT and TUG.

Because of the lack of effect found in the use of the commercial exergames (such as the Nintendo Wii system) in larger health areas, the review on activity-promoting gaming systems in exercise and rehabilitation by Taylor et al. [186] arrived at the conclusion that a "potential limitation of the available commercial games and gaming systems, even though they encourage improvements in balance, strength, and fitness, is that they are not necessarily designed for rehabilitation." [186],p.1183

Indeed, the presented study suggests that exergames designed specifically for prevention and rehabilitation can have a significant effect in a fast manner. With the modular interactive tiles and the games that were designed specifically as exergames for enhancing physiological and cognitive abilities in a playful way, it is possible to observe significant effects. The design was targeted the health area and with prevention and rehabilitation in hospitals, care and rehabilitation institutions, and private homes in mind, and this focus led to the development of a platform that is easy to adapt to health interventions, to individual levels, to progressive levels, and to different environments.

This kind of exergaming design of hardware and software targeting prevention and rehabilitation can be exemplified with the exergaming design for falls prevention. The systematic review and meta-analysis by Sherrington et al. [179] found that the greatest effect of training on reducing falls was obtained from programs that challenged balance to a high extent. They showed that "moderate- or high-intensity strength training was not found to be associated with greater effect of exercise on falls", that "exercise programs that did not include walking reduced fall rates more than did exercise programs that involved walking", but that "inclusion of balance training in exercise programs appears to be important." [179],p.2241 Furthermore, the Cochrane review by Gillespie et al. [66] found that multifaceted interventions can prevent falls in the general community, in those at greater risk, and in residential care facilities.

With this important knowledge in mind, we designed a technology that challenges balance in a multicomponent way when the subjects are playing physically interactive games on the modular interactive tiles. Each of these physically interactive games simultaneously challenges many components of the subjects' physical and cognitive abilities. The modular interactive tiles games enforce activities that combine physical training with sensory tasks and cognitive tasks. Some of the games are consequently designed to promote unpredictable, sudden movements, and the games allow for a gradual increase of difficulty. Even the modularity of the tiles allows games to progressively change level merely by changing the physical platform [178].

In her review, Shubert [199] concluded that home exercise programs should be structured, be progressive, incorporate different components for balance training, and increase in difficulty in order to challenge the patient's skills (e.g., vary exercises for even greater challenges). With the simple adaptivity to a patient's level done by changing the physical platform (e.g., putting a few less or a few more modular tiles in the platform) or by changing the game level by swiping a new game card with a different level, the modular interactive tiles and their games seem to be suitable for such home exercise programs. The intervention presented here can be viewed as an initial training that quickly improves the performance of the elderly, and it seems feasible to continue the exercise on modular interactive tiles with different games and levels or over a longer period of time afterward to create a longer duration intervention for patients at risk of falling or at risk for other significant health issues. An important aspect of a longer continuation of training is that users find the playful exercises with modular interactive tiles to be highly motivational and fun [18, 178].

In conclusion, compared with related work on effect studies of general fitness interventions (e.g., strength training, aerobics, cycle and circuit resistance training, balancing training, walking, Tai Chi, etc.) for community-dwelling elderly, which show significant effects on only a selected set of health parameters, surprisingly, this study demonstrates significant improvements on all tests after short-term training with the modular interactive tiles. It also shows a high level of improvement in gait speed. It is noteworthy that significant effects were obtained on all of the tests performed and that significance was obtained after just nine playful training sessions with the modular interactive tiles. This effect was found despite prior literature noting that many more sessions are needed with the traditional training in order to obtain any effects. The results presented here show that exergaming can have a large effect on community-dwelling elderly individuals when they are training in a playful manner with the modular interactive tiles.

B.6 Acknowledgments

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B.7 Author Disclosure Statement

H.H.L. is a director of the Entertainment Robotics Company, which produced the modular interactive tiles. J.D.J. declares no competing financial interests exist.

Paper C

Physical computer games for motivating physical play among elderly

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Keywords: Physical computer games, motivation, physical training, elder

C.1 Purpose

To avoid falls and stay healthy, it is important that elderly people preserve their muscle strength. Therefore, physical training for the elderly remains an ongoing area of research. Current training methods consist primarily of rehabilitative training and/or optional exercise classes with a physiotherapist or volunteers. This paper presents a new solution that motivates elderly people to engage in physical training by introducing simple, fun, and challenging physical computer games.

C.2 Method

In the project we use modular playware tiles (Figure C.1) [18]. The tiles were used in two elder centers (16 participants, averaging 79 years old), a rehabilitation center (12 participants, averaging 79 years old) and a hospital (12 participants, averaging 85.33 years old). Each week, there was 1-2 training sessions, and care was taken to ensure that each participant received at least 12 minutes of training in each session. Observations and informal interviews where performed during the sessions. The data were categorized and analyzed using theoretical coding.

C.3 Results & Discussion

The introduction of physical computer games on modular tiles for elderly participants was highly motivating and very successful, corresponding with results from other user groups (i.e. rehabilitation patients and children [200]). There was special interest in memory games that challenged the elderly both physical and mentally. The coaches asked for 2 minutes of training time for each game, but the elderly kept playing for up to 10-15 min of a single game. The games created a playful atmosphere, which improved motivation compared with standard rehabilitation training and exercise. Several participants complained they did not have enough time to play. There was a high degree of competition among the elderly players for most points, and against themselves to beat their own records, which indicates that games can improve exercise time and intensity. This was supported by participants' physical improvement; measurements at the elder centers showed improvements on Chair Stand 24%, Timed Up and Go 21%, 6 Minutes Walking Test 29% (tests from senior fitness test [30]), Tandem Line Walk 66%, for all $p<0.001$) and measured at the rehabilitation center where improvement on Dynamic Gait Index was 12.3%, $p<0.05$)4. Thus, play on modular tiles seems to create a strong motivation for participation in therapeutic activities, as well as measurable health improvements, among elderly users

Figure C.1: Modular Playware Tiles.

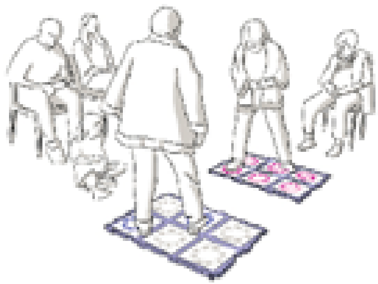

Figure C.2: Playware Tiles in use in an elder center

Paper D

Games as Actors - Interaction, Play, Design, and Actor Network Theory

D.1 Abstract

When interacting with computer games, users are forced to follow the rules of the game in return for the excitement, joy, fun, or other pursued experiences. In this paper, we investigate how games achieve these experiences in the perspective of Actor Network Theory (ANT). Based on a qualitative data from a study of board games, computer games, and exergames, we conclude that games are actors that produce experiences by exercising power over the user's abilities, for example their cognitive functions. Games are designed to take advantage of the characteristics of the human players, and by doing so they create in humans what in modern play theory is known as a "state of play".

Keywords: computer games; board games; Actor Network Theory; interaction; game research; game design; play theory

D.2 Introduction

Using computer software usually implies that the user is the active part who controls the interaction by input and direct manipulation [201, 202]. Interaction with computer games is a different experience because the user acts in a game world where the contents of the game has extensive influence on the gamer's behavior. Game figures and other game items are not just passive objects that can be manipulated by the gamer. For a game to come live, gamers have to follow rules and act as the game requires. Playing a computer game like Counter Strike or World of Warcraft is not just a question of manipulating an avatar. The game is forcing the gamer to react to events in the game by acting in a certain way if he wants to survive and prosper in the game, i.e. the gamer is placed in a role he has to fulfill. In other words: games do something to and with people who play them and, in a certain way, games are just like actors who have an agency. What this agency consists of and how it is engineered is of interest to designers.

In this article, we will demonstrate how games can be seen as actors and as organizers of actors and actions on the basis of Actor Network Theory (abbreviated to "ANT") [111]. ANT is well suited for the analysis of interaction with games by users since ANT offers an approach to agency that does not assign power only to human actors but allows the possibility for objects and rules to be examined as actors. Also, ANT opens the door to viewing design as a social enterprise. As Yaneva stresses: "... design has a social goal and mobilizes social means to achieve it" [203].

ANT has received some attention in game studies during the last decade. Several scholars have studied games on the basis of ANT [204], focusing primarily on the interchange between humans and technology [205] or on the development of social networks in online games [206]We take a different approach and show how the ANT perspective can explain which forces are at work when games are actually played. Our focus is thus on defining the immediate effects of using games. Our approach is in line with Seth Giddings [207], who have analysed games from the perspective of ANT. Giddings stresses that "the analysis of video games [...] demands the description of a special category of nonhumans, software entities ([...] agents] that act more or less autonomously or effect emergent behaviour" [207].

The article is the result of a research project where we studied gamers of different ages playing computer games, board games, and digital play equipment. Contrary to Giddings and other scholars studying computer games, our point of departure was the theory that computer games and other games based on digital technology are games before they are anything else [206]. They are not first and foremost technology. Therefore the study is focused on studying games as a genre rather than just digital games, and our main example here is a board game.

In the next section, we will introduce ANT focusing mainly on the concept of "translation" which is employed as our main analytical foundation. After this, the paper will present the research methodology applied for collecting data. In the following sections, the selected case of game playing will be presented followed by a presentation and a discussion of the results of our investigation. In this section we will also draw on modern play theory to further explain how and why games function and also why computer games belong to the general genre of games. We conclude this article with reflections on how our viewpoint influences design.

D.3 Actor Network Theory

ANT was first developed by science and technology study scholars Michael Callon and Bruno Latour [115] as a new approach to social theory. ANT is of interest to any analysis of technology which goes beyond the assumption that technology is a mere instrument that we, as humans, utilize. ANT claims that any element of the material and social world (nature, technology, and social rules) can be an actor in the same way humans are. Agency is never only human or social but always a combination of human, social, and technology elements [112, 113, 114].

ANT is not a theory in the usual sense of the word according to Latour himself, since ANT does not explain "why" a network takes a certain form or "how" this happens [111]. ANT is more a method of how to explore and describe relations in a pragmatic manner, a "how-tobook" as Latour defines it [111], and, as such, it offers a way to describe ties and forces within a network.

The main idea of ANT is that actions always take place in interaction between actors in networks when actors influence each other and struggle for power. We usually see social interaction between humans this way, however, ANT differs from traditional social theory by stating that the actors are not only humans but can be other elements as well.

D.3.1 The traffic example

ANT can be difficult to grasp and even counter-intuitive [114] because it reverses our common understanding of actors and agency, e.g. when it cuts across the subject-object division underlying our thinking about the world we live in. In an attempt to clarify ANT, Hanseth and Monteiro [208] use traffic as an example to explain the implications of seeing something in the perspective of ANT. We find their example very useful in obtaining a better understanding of ANT and, hopefully, what we later have to say about what games do. The following is a short presentation of their attempt and afterwards we will use it to explain the process of translation: When you are driving in your car from one place to another, you are acting, however, your acts are heavily influenced by technology, the material world (maneuvering abilities of the car, layout of roads, traffic signs, traffic regulation, etc.), and the immaterial (traffic rules, traffic culture, etc.) and habits (your own behaviour as a driver) [114, 208].

According to ANT, these factors (including you) all function as actors and should be understood as forces of agency in a linked network. If you want to play the game, human and non-human, technical and non-technical elements are part of the network, and none of the elements are per definition granted special power over the others [208].

Expanding the thoughts of Hanseth and Monteiro, we can add that, in the traffic example, you want to move from place to place, but you are dependent upon technology and forced to act in accordance with both social rules and physical conditions. Even though you are the driver, you will clearly feel the forces of other actors when acting out the driving. For instance, the road forces you to follow a certain route, the traffic light forces you to stop and start. One can say that in order to reach your goal safely and quickly, you have to "give in" to the network and in a way "hand over" your acting power and control over the car, so that the vehicle will move in accordance with the demands of traffic network. You have to "delegate" [114] power to the traffic network, and, in return, you will reach your goal as fast and safely as possible. Of course you are not handing over the control of yourself to the network. To delegate is more to act as prescribed by other actors. According to ANT, this is what happens in an actor-network relation.

D.3.2 Translation

The way delegation is done is through the process of translation. This process requires the actors in a network to accept roles, a worldview, rules of acting, a path to follow etc.. Michel Callon [116] describes the process of translation as a process of "persuading" with four distinct phases, he calls "moments": problematization, interessement, enrolment, and mobilization. These moments are inter-related overlapping steps that describe how stable actor-networks come to be established [209]. We will introduce them briefly in the following, and later use them in our game analysis.

The first moment, problematization, is where some of the actors in the network in question bring forth a definition of the problem and present a viable solution to it for the other actors. This is also the process during which the actors' roles are defined (both human and non-human actors). To use the traffic example above, this is where the car and the traffic network are presented as a solution to the transport problem.

As part of the problematization process, a so-called obligatory passage point (OPP) is defined, i.e. a practicable solution, which the actors have to accept to achieve their goal. An OPP "is viewed as the solution to a problem in terms of the resources available to the actant [actor] that proposes it as the OPP (...) It controls the resources needed to achieve the actant's outcome." [210]. By defining an OPP, other possibilities are closed [116]. In the traffic example, the OPP is literally a passage, since it's the roads and the current traffic rules etc., which have been established as a solid, reliable network.

The second moment, interessement, is where the main objective is to convince all the involved actors that the proposed problem and solution is the correct one so that they will accept to use this solution and not another one. In the traffic network, this is done by the use of sanctions from traffic rules, signs, and, not least, by the learning processes human actors go through to get a driver's license.

When the interessement of the actors is successful, the third moment, enrollment, is happening. This moment is important since it is here that support and allies are created, and the process by which actors become part of a network. The process can happen in many ways: "To describe enrollment is [...] to describe the multilateral negotiations, trials of strength and tricks that accompany the interessements and enable them to succeed." [116]. In relation to the traffic network, one can think of all the things that support cars and their moving along the roads.

Finally, the last moment, mobilization, is where the actors are mobilized in such a way that they act in accordance with their prescribed roles and thereby maintain the established network. This happens when the drivers drive their cars following the rules and pathways of the traffic network.

D.3.3 Design as inscription

The effect of translation is delegation of power and agency. In relation to design of objects, e.g. computer games, translation is about how to construct an object in such a way that users are convinced to delegate agency. This is described as inscription and description by Madeleine Akrich [117].

Inscription is the process where a designer embeds a special way the user has to interact with the designed object. The designer is envisaging a user and a use case for the object and develops an intended use, which is inscribed into the object by use of, for instance, physical shape, GUI, behavior of objects, and affordances in general.

Akrich compares inscription with a movie script and calls the result a script for how the user should use the object. We see thisin the design of e.g. the user interface of an iPad, where users are compelled to use finger movements to interact which are a more intuitive way of interacting and quite different from using a computer mouse.

While inscription is the designer's idea and framing of the interaction, Akrich uses the term description to describe the actual usage of the objects. This is where the script, built into and drawn upon in the design process, meets the user in an actual user setting. Coming alive is the central part of description. It is central to ANT that a non-human actor can have agency and perform actions and this is what we see when scripts, embedded in designed objects, come to life and objects engage in a network with other actors.

In the perspective of ANT, a game can be studied as a designed object with inscriptions that has agency and does something with the user, because the user invokes a network of actors and agency when he starts playing a game, i.e.

following the rules of the “game world”. A game designer has to be aware of the network of actors that the specific game design can invoke if he wants to be able to use it in the process of inscription. Networks of actors represent the unit of analysis in our study presented below.

D.4 Research Methodology

Our research method relied on qualitative data collected through observation, based on non-participatory observation as well as active participation and interviews [211, 212]. We collected data from 12 game sessions during which we observed informants, recorded their behavior and interviewed them before, during, and after playing. To ensure recordable data, we used games in which players had to be social and communicate with one another and board games was particularly well suited for this since people tend to talk more when playing such games. We observed children as well as grown-ups and mixed age groups playing games in natural settings at home in a family situation or with friends. We recorded spoken language as well as body language and managed the many data using thematic and theoretical coding as described by Uwe Flick [158], who is inspired by Grounded Theory [213]. The analysis of the collected data was of course done using ANT. Researchers from social science have demonstrated that ANT is well suited for exploratory research in areas that have not been investigated much, not least because ANT-driven research is often able to draw up new conclusions [209, 214, 215]. The purpose of our study was to investigate and describe agency and actors at work when gamers play games. As our framework of analysis, we employed the concept of actors and agency and the four described moments of translation, being careful not to differentiate between non-human and human actors. We analyzed agency by following what people did with games, extracting actors and ties, and described the translation process in the actual game situations, as we will demonstrate in the next two sections. These sections are also reports of ”findings” from our study. As Kraal [209] writes with reference to one of the founding fathers of ANT alongside Latour, John Law: ”It is the nature of ANT that it is easier to describe through a demonstration of its use”.

It is important to mention that the object of our study is not the games themselves, but the event that unfolds when games are played [207]. In accordance with ANT, we analyse games in action when the forces of the network are at work, so to speak.

D.5 Case: The Game "Quackle!"

The case of playing the board game "Quackle!" in a mixed age group is used as an example for our observations in general and in the following we will use our analysis of this case to present our interpretation of what the game actually does.

D.5.1 Quackle! The game

The game, which was awarded "Game of the Year" in Denmark in 2006, is a typical funny board game for humans aged 5 and above. In short, the game consists of 12 different animal figures, 8 barns, and 97 playing cards with pictures of the animals and one arrow card (see Figure 1). The game starts with each player pulling an animal figure from a cloth bag showing it to the others and then hiding it in his barn so the others can no longer see it. The cards are dealt and placed in a pile in front of each player face down.

The objective of the game is to get rid of all the cards you have in your pile. Each round of the game consists of the players in turn turning a card and placing it for all to see. If two players have the same animal on their card they enter a battle during which the players compete on being the first to loudly say the sound of the other player's animal hidden in the barn. The player who looses the battle must pick his own and the pile of upwards facing cards of his opponent. The game continues until once again there are two identical animals in the cards or one of the players gets rid of all his cards [215].

The game seems pretty simple, but requires that the players can remember and quickly mobilize the correct sounds when two identical cards are turned, which is more difficult than one might think, even for adults.

D.5.2 Game inscription

As we see in the above description of the game, there is a special way players are expected to interact with the game (the inscription) and, as we will argue in the following, in this way the game uses the learned scripts that the player brings along as well as physical and psychological abilities of the player. Among other things, the game takes advantage of the knowledge of the players (i.e. scripts) about animals and animal sounds, and the game utilizes the fact that most humans have a tendency to react automatically in pressurized situations. It is precisely this automatic reaction that makes the game funny, because the players make lots of mistakes trying to be the fastest which often result in weird sounds that is a mix between different animal sounds.

The game designer has created an inscription that can be indicated as follows: We must say a particular animal sound while we see and try to remember a lot of other animals. These many inputs are combined with the stress factor that the game introduces by stating we must respond faster than our opponents! Thus, the inscription creates a special way the player has to act, i.e. a specific way the players have to use their abilities.

In the perspective of agency, it is noteworthy that the game forces the player to make mistakes and thereby produce a mishmash of sounds which he would not normally produce. When asking our informants about the experience, most of them said their tongue was "out of control". In this sense, it is evident that the game has agency and does something to the player.

D.5.3 Translation

The inscription plays an important role when considering the whole situation as a translation. As previously described, the translation consists of four moments which we will now outline in relation to the game scenario.

The first moment is the problematization, which is where we are presented with a problem. In our case, the game is played in natural situations on a Friday evening in a family of four (parents and two children, son aged 12 and daughter 21). For the family, the problem is the need for entertainment understood as a peaceful and enjoyable social time together. In this case, the game of Quackle is set up as a solution. Like any family game and most entertainment products, it promises that playing the game will lead to the experience of fun. Thus, the game is put forward as an actor who can do a piece of work (give us fun) through the way other actors treat it. This happens when one of the family members says, "Let's play Quackle, its fun. We always laugh so much when we play it." (quote from the daughter in this case).

The game is put forward as a solution and as the obligatory passage point (OPP) to social entertainment. The solution simultaneously suggests roles and organizes relations, i.e. a specific network where the family members will become game players and the living room table and chairs to facilitate the family sitting together. No less important is it that the game will establish equality between the players regardless of age and family position.

In the next moment, the interessement, which actually takes place in parallel with the problematization, the family members are convinced the proposed solution is the right one and barriers for alternative solutions to the problem are added. One of the things that are cut off is television; a frequently used source of entertainment in the family, when one of the adults says: "We shouldn't watch television, we always do. We should do something together instead." (quote from the episode).

Enrollment is the third moment where the players are enrolled and this entails that they must accept the roles of participants as players of Quackle and accept the terms of the game.

In the last moment of translation, mobilization, the solution is executed when the family members sit down with the game and start playing. If the mobilization works and the translation process is thus successful, it enables the family to experience fun and laugh together. This is exactly what happened to the test family via the interaction with the game, which created a lot of laughing especially when the parents made weird sounds.

In our observations, we also encountered an event of a failed translation. In this episode, which involved four adults and two children, the setup was similar to the above but the one of the players didn't accept the role of a player who could end up saying a wrong sound, and thus she ended up destroying the game. She didn't hand over agency to the game and didn't act as prescribed by the game.

This episode was special, but its points to the fact that the translation can fail and the players have a choice, though this choice comes with certain consequences (they never got in to play).

Going back to the situation with the successful translation, the game reorganizes the social connections within the family and in so doing builds a new network of actors and agency. The game is what Latour has named a "mediator" that "transforms, translates, distorts, and modifies" relations [114]. But the game does more than alter the social relations. It mediates the body and mind of the individual players. In the following, we will address how Quackle accomplishes the mobilization of the physical and cognitive abilities of the players.

D.6 What the Game Does

A game cannot do much by itself but is dependent on other actors, and this is, of course, particularly true for board games. Nevertheless, games have agency that makes game players act in a manner they would not have acted without the game. In that sense, the game "does" something in line with Latour's concise statement on what defines an actor: "anything that does modify a state of affairs by making a difference is an actor [...]" [203].

Latour stresses that when we are studying a network in ANT, we are focusing on the circulation between the connections that make up the network [209]. When we look into the Quackle game, we are looking at how agency is floating between the involved actors, the details of which we will try to demonstrate through an analysis of a play scenario.

First, the scenario of a family playing the game:

1) The game is placed on the table and the players sit down around it.

2) The game is opened, and the game elements are displayed. There are animals, barns, and cards and a cloth bag.

3) The animals are hidden in a cloth bag and all players get a barn.

4) Each player pulls an animal from the cloth bag: Player 1 gets a snake, player 2 a dog, player 3 a donkey and player 4 a frog.

5) After all animals and sounds have been introduced, they are stored out of view in the barns.

6) The cards are shuffled and dealt.

7) Everyone is ready and turn their first card.

8) A horse, a cow, a duck and a pig is turned, so there is no match.

9) Next cards are turned: a snake, a pig, a frog and an owl appears, still no match.

10) The third cards are turned: A mouse, a donkey, a rooster and an owl appear.

11) The game gathers speed and the cards are turned a bit faster.

12) The fourth card is turned: a cat, a dog, a cat and a frog.

13) Player 1 shouts "Qu..iau" [sounds a combination of a frog sound and a cat sound] and player 3 "Vu..sh"[a combination of dog sound and snake sound] followed by a grinning "Oh no, uh" and finally player 1 says "Miau" just before player 3 says "Sssshh".

14) Player 3 must gather player 1's card and the game continues.

This is the basic structure of the game which continues in a similar manner for a long time (about 30 minutes) before a player wins.

Points 1 and 2 are of practical character, but they help to create the framework for what is going to happen. Thus, the following activities are framed and the game's inscription starts to become clear, especially in the form of the rules. The agency is still with the players. This is also the case in point 3, but here the game starts to gain agency. It starts to have an effect on the players, as it prescribes their actions in the next steps.

Our observations show that, at the same time the players build up anticipation about what is going to happen which is seen by the body movements and heard by the tone and pitch of voices, this anticipation started when the players accepted the game as an OPP. It was especially noticeable in point 4 and 5 where the joy of hiding the animals in the cloth bag and pulling one provides a form of excitement that is particularly evident in the youngest child. Thus, we see here that the agency is distributed to the game as a kind of pre-disposition of body and mind [204].

In point 5, the players need to remember all the animals the other players have. The individual player has to establish links between the different animals and the players around the table. In point 7, the number of links is expanded by the creation of connection to the cards and in point 9, the game is made even more complex as more animals are introduced and it makes it harder to remember the animals hidden in the barns, which is of course part of the game designer's inscription.

We continue to point 13, where we see the first match of cards. When this match appears, a special script appears which is part of the inscription of the game. The script forces the player to act as prescribed by the game rules and it thereby functions as a type of mechanism that governs the actions of the players. The mechanism re-organizes the connection between the player's body and cognition in a special way by means of rules and materials (cards, animal figures, barns) and, in this manner, the game utilizes the functions of the player. As mentioned earlier, the player is driven to make mistakes when pronouncing words, and it is this "drive" that demonstrates an agency from the game.

What the game does can be described as follows: First, it mobilizes the individual player's memory but overemphasizes the need to remember. There is a wide range of images, sounds, figures, and places in play, and the player will have to revive all of these objects and connections when the match of cards happen. There are different animal figures and their sounds to choose from, and several sounds usually become actualized before the players are able to produce the correct sound.

Secondly, the game cuts across the usual connection between the player's mind and body. In point 13, it is clear that the game disrupts the usually well-controlled connections between the player's cognitive ability and their ability to control their voice. The inscription provides a procedure for a specific requested response to certain signals where the player has to use specific cognitive functions, i.e. perceive, remember, associate images and sounds as well as mobilize the organs of speech; and it all has to happen as quickly as possible. It is a simple task that players do not usually have problems with but, by adding a wide range of signals in the form of different images and sounds, and, by forcing the players to compete with others, the result is that cognitive and bodily functions respond in an incorrect manner and the players end up making wrong sounds. The game has, in a way, taken over body and mind.

The case of playing Quackle is an example of a translation process in action, where agency is delegated to a network. The case is also an example of how such a network is comprised of human, material, and social actors. The translation is only happening because the players have allowed themselves to be enrolled as players and fulfill their roles by using the material and following the rules and thereby delegating agency. In return, they are entertained.

D.6.1 Playing a computer game

Earlier in this article, we stated that we consider computer games to be games before anything else. Thus, our thesis is that computer games do something to the players when played, just as in the case of Quackle What we have attempted until now is to establish a framework for analyzing what games do, and, in the following, we will briefly show how the framework could be applied to computer games.

The setting, which we observed, are three boys 12, 12, and 14 years old playing Grand Theft Auto V (GTA) on a Playstation 3. GTA has become very popular with its mixture of racing and adventure, where the players can follow a story already inscribed in the game or they can just go racing around in the game city.

The boys take turns at controlling the game while the two others comment and talk about what is happening. In one scenario, the 14 year old is controlling the game. He gets an assignment from the game where a tough looking guy on the screen tells him that he needs to win a race with a computer-controlled opponent to progress. Then the game begins.

The setting, we are analyzing, is a network that consists of the interior (couch, table, etc.), the Playstation (consisting of screen, game console, controller and DVD), the three boys, and the game. The game itself consists of multiple actors of which some are activated in combination with the other actors of the network.

We will not analyze all actors and possible networks the game can initiate but will only take a short look at how the game impacts the players' bodies.

When playing, the boys have to follow the rules of the game. They are complicated, but for our example here we can just point to the traffic rules in the game and how the car is driven via the controller. In the same manner as in a real traffic system, the player has to delegate agency to the system. Just as in the real traffic, there is police; here in the form of multiple cars and helicopters, and there are roads, houses, pedestrians, and the normal traffic on the road, all i of which have to be avoided during the race. All of these actors become active as the boy starts the race which lasts for a few minutes.

It is apparent how the game influences the player's body. To initiate the game, the boy presses hard on the controller and swings it forward, and the next second he and the controller are leaning heavily to the left side, almost leaning into one of the other boys. The next second, all of the boys shout "Wow, that was close!", while they all jump a little in the couch. At the end, they are all standing up and leaning forward and to the side as they follow the movements of the car on the road it tries to follow.

If we look at this scenario as a translation, we can see the problematization is set forward as the boys need to win the race and this is also the OPP. In the interessement, the game builds on the fact that the boys are already enrolled in the game (emerged in it) and thus they need to progress to keep playing. The enrollment is made more stable by the use of a character in the game and adding a storyline to the race (why they have to win), thus agency is transferred to the game. This also builds up the tension for the next moment, where the boys are mobilized to play. The term "boys" indicates that all three boys participated even though two of them didn't control the game.

When the race begins, the boy controlling the game is leaning forward and swinging to the side with his body. This is where the game uses some of its agency and the bodily action of the player shows that the game is mobilizing the player's ability. In our observations, we saw this again and again, the players could not help it but move their body to the side as they turned a corner, even though in this game it wasn't needed, as the controller doesn't react to it.

The game further uses its agency when it makes the boys shout and jump. This happens as the car almost hits a wall that would have crushed the car and made them lose the game. This kind of danger is present all the time in the race. Here, the game is exercising its agency by using the player's body and mind, including his imagination that allows him and the other boys to experience danger, which in the real world would have produced fear but, in the framework of the game, produces excitement.

D.7 Theory of Play and Games

Obviously, excitement or pleasure is the reason why game players obey to the demands of games in the way we have described above, i.e. accept to act as a node in a network, following rules they often do not understand, using hour after hour trying to learn to manage game challenges. What games do is to produce play and playful experiences for users. In the following, we will lean on modern play theory and modern game studies to clarify the importance of play and the connection between games and play.

One need not search for long in game studies literature before it becomes evident that play, according to most researchers, is an important factor for the success of computer games as well as other kind of games. Prominent play scholars like Johan Huizinga, Roger Callois, Gadamer, and Brian Sutton-Smith appear as references in numerous articles and books on the topic. In Salen and Zimmerman's well know book on games, Rules of Play [93], the authors define the goal of successful game design as "...the creation of meaningful play..." [93] and later on state that "...rules are merely the means for creating play..." [93]. And to make the central point absolutely clear, they argue in a subsequent anthology on games that "...games create play: of that there is no doubt." [94]. In other words, games fulfill a function in relation to play.

In line with our view presented here is also [11, 97, 216]. Games can be seen as "tools" that generate play, and, more importantly, games must be designed with the aim of generating play.

But what is play? In developmental psychology, play is primarily seen as a means for learning (Piaget [217], Vygotsky [218], Singer, Golinkoff, & Hirsh-Pasek [123]) and, in that frame of reference, it follows logically from the statement that games generate play that they also generate learning. Modern play theory sees play differently. Based on the work of the above-mentioned play scholars, play is regarded, in and by itself, as a meaningful human activity that we practise for the simple joy of it. Game players accept the translation of agency to games simply because they can get into play by doing so, or more accurate get into the condition in play theory called "the state of play", derived from Johan Huizinga [96] who is probably the most quoted play theoretician today. He writes in "Homo Ludens" (which translates to “man, the player”) about play this way:

“... what actually is the fun of playing? Why does the baby crow with pleasure? Why does the gambler lose himself in his passion? Why is a huge crowd roused to frenzy by a football match? This intensity of, and absorption in, play finds no explanation in biological analysis. And yet in this intensity, this absorption, this power of maddening, lies the very essence, the primordial quality of play. [...] ... it is precisely the fun-element that characterizes the essence of play. Here we have to do with an absolutely primary category of life, familiar to everybody. [...] the fun of playing resists all analysis, all logical interpretation...“ [96].

The last sentence is perhaps the most important for the understanding of play and, thus, for the understanding of what games should be designed for. Play is a difficult concept to define in a scientific context because of its nature as an activity, which represents other values than the ones we traditionally use and base our thoughts on. Both in science and in our daily lives, we usually try to rationalize human activities and give them a purpose. When it comes to play, it is not possible to apply rational reasoning according to Huizinga, and play does not submit itself to the usual rational notions. We are forced to remove our accustomed patterns of thoughts and recognize that the human being is something else and more than a rational being. In short: Human beings want to play for the fun of it, and we use games primarily because they can get us “absorbed” in play.

Games, whether board games, computer games or other kind of games (of which we will present an example shortly), should be designed to facilitate this absorption. Traditional games like street games that have been around for long, some for hundreds of years, are clearly designed to produce the joy of play [97]. Games are some of the first things we meet as infants when we learn to communicate. Play researcher Brian Sutton-Smith have given a most precise definitions of play, which is useful to game design, even if it is about infants:

“[...] we postulate as the aboriginal paradigm for play, mother and infant conjoined in an expressive communicational frame within which they contrastively participate in the modulation of excitement. We call this a paradigm for all ludic action, because we suggest that other play itself is a metaphoric statement of this literal state of affairs. Ludic action, wherever it is, always involves the analogous establishment of the secure communicational frame and the manipulation of excitement arousal through contrastive actions within that frame.” [95].

“Modulation of excitement” is a very precise description of what games do. There are numerous variations of such modulation. For instance, play can be physical, making the body move forward and backwards, as in sports, dancing, or on a swing; it might be psychological, creating and using a mental tension, for which jokes or horror stories are good examples. It is remarkable in this context that play if often generated by directly using the natural reactions of the body and mind, e.g. dizziness or fear, as we have tried to show in our game analysis.

We employ countless forms of materials, techniques, or genres of physical as well as immaterial types to help initiate activities that make us play. Thus, games are just one out of numerous tools [11, 93, 97, 216]. From the simplest tools, for instance the games of dizziness, where young children turn around and around to get the excitement of dizziness, to the computer games the goal contains a familiarity. In the next section, we will present games ased on high tech, where we have utilized knowledge of games as tools for play.

D.8 Exergames

Exergames is one of the many names for a fairly new type of games. These games try to combine physical exercise with digital games through an interface that requires physical exertion to play the games [2, 35].

Exergames are interesting here because they combine the physical abilities of the players with the opportunities of the digital games. At the same time, many of these games are less complicated than computer games like GTA, because they rely on the physical aspects and movements of human players and less on the virtual world’s narratives. This allows us to further investigate how the human players are being used within the network of a game.

In the following, we will look into one type of exergaming called modular interactive tiles (“tiles” for short).

The tiles (displayed in figure 2) are a distributed system consisting of electronic tiles, which can be assembled like puzzle pieces. The tiles combine robotics, modern artificial intelligence, and play in a product that can be used for games, sports, health promotion, rehabilitation, dance, art, and learning [2].

Every tile is 30 x 30 cm and works independently but is able to communicate with all the surrounding tiles. In this way all the tiles can communicate with each other and create a playfield for the players to play on. The tiles have a force-sensitive resistor and eight RGB light-emitting diodes able to shine in a rainbow of colors.

The many colors allow for a variety of different types of patterns and games to be played. To play a game on the tile platform, a player must move around and step on the tiles according to the rules of each game (see later). The various applications can either be played by a single person or can be set up so that multiple people can collaborate or compete against each other.

Because the tiles are designed to work in any combination and because of the puzzle piece design, the tiles give the user the ability to create any playing field they wish, and to change it again anytime - e.g. change the size or shape of the field of tiles. When the user changes the configuration of the tiles, the interaction and difficulty is also changed, e.g. faster/slower movements, longer/shorter steps and so on. Thus the user has the ability to change the movement and difficulty merely by physically building a different kind or size of the platform.

The tiles have been used as balance training for elderly people (65+ years old) and motor skills training for children (5-6 years old). We observed both elderly and children (total of 20 sessions for each group), but here we will focus on the sessions for children. Each participant participated in 10 or more sessions and a total of 19 children participated.

The data were analyzed using the methods described earlier and the following account is a prototypical example of the use of the tiles for children even though similarities exist in the use for the elderly. This example illustrates the main findings and forms a good basis for the ANT analysis. For the sake of the analysis, we are focusing on one game called "Color Race", (see [2] for more info on the tiles).

The game "Color Race" is a type of "Catch the Color" game. On the playing field, three tiles is randomly displaying different colors – red, green, and blue. Each player chose a color and has to step on the tile with the chosen color as fast possible. When they step on the tile, its color shifts randomly to another tile on the playing field that the player now has to step on.

The player has to step on tiles with their chosen color as many times as possible within a given timeframe (typically 30 sec). When the time is up, all tiles light up in the color that got most points. Hopefully the reader can imagine three players running around on the relatively small playing field at the same time trying to step on tiles as fast as possible. The stage is set for rough-and-tumble play (in our experience regardless of age).

In the scenario that we believe is a prototypical example of the use of the tiles, we are in a kindergarten with 10 children 5-6 years old and an adult. The room is full of other toys, but there is room in the middle of the floor for the tiles. They also have chairs that some of the children are sitting on while they are waiting to play. Others are standing around and cheering or observing the children playing. The children are playing with the tiles two times a week, so they know them at this point. The adult helps to set up the tiles and they are placed in a typical setup of 9 tiles in a 3x3 square, and the game Color Race with three colors is started. Three of the children pick a color each, and they place themselves in front of that color and count down to start.

As soon as they start the game, they jump from tile to tile trying to get around the other players, but they keep bumping into each other again and again as the playing field is approx 1x1 meter so they don't have much space to move on. The game lasts for 30 seconds where the players jump around and get around 20 points each. At the end of the 30 seconds, the tiles light up in green showing that the green player got the most points.

As described above, the game requires the player to step on the tiles for the game to proceed. Here the inscription is the tiles in general and the game of "Color Race" in particular is calling for the player to step on the tiles. In our observations, we have seen this time after time. New players or observers can't resist trying to press the tiles to see what happens. The physical design of the tiles on the floor, the size of a foot, and the colorful light invite the player to step on them. They function as trigger points.

If we look at the inscription, it can be described as follows: The player must press a tile and catch as many lights as possible within a limited time frame. The game is created so the color jumps to another tile almost instantly and this creates the feeling of running after the colors, thus the name "Color Race". The movement of the light to another tile “forces” the player to act as prescribed be the game rules but also the surrounding network of competing with other children, and the observers cheering on is contributing to this “force”. This is another example of what we saw earlier with Quackle! where the players are driven to act in a certain way.

If we look at the description, it can be described as follows: The player must press a tile and catch as many lights as possible within a limited time frame, which organize both body and mind of each player and the interaction between them. The game also creates the necessity of speed by organizing the game as a competition. All the sessions we observed with children involved multiple players on the platform, and with more players at the same time, there is also an element of competition and a lot of communication between players. Notably, the kind of friendly communication connected to play and games. It is noteworthy that all of the players, we have observed, talk, shout and laugh. The game evokes a kind of friendly play fight.

It is of special interest from our viewpoint that the game sets up the players not only as players, but at the same time as material obstacles in the game. In the scenario with the tiles, the players are all playing at the same time and the colors jump around the platform. Here the game is using its agency. As pointed out above, the game is forcing the players to move from one tile to another, but in the process it creates a “double” role for them as players also become obstacles for other players. This “double” use of the human player is important for how the game functions. Each player becomes a game element, as they again and again are standing in the way of others who are trying to reach a tile with their color.

In the observations, we could see that exactly this point was critical for how much fun the participants seemed to get out of the game. If they surrendered to the game and accepted and maybe even used the fact that they bumped into each other, they seemed to enjoy the game more. Often players tried to push, pull or bump the other players away so they could easier reach a tile.

The game is also pushing the players to speed up and jump around by shifting the position of the light almost instantly as the tile with a color is pressed. It creates the effect of the game progressing fast, and players indicated that they felt the need to hurry to the next tile even though the color will stay there until pressed. Technically there was no need to hurry but mentally it appeared so.

If we consider the case as a translation we can then observe the problematization as the case of the children wanting to get into play (the state of play or play mode), and the tiles are put up as the OPP. In the interessement, the children are convinced that the tiles are the solution to the problem and the roles are divided with the children as players and obstacles for each other, the tiles as the playground and the place the game will take place.

The children and tiles are enrolled and they accept the roles in the enrollment and they accept the rules of the game, they accept that they will become both active players and obstacles in the game.

In the final moment the actual game is played. The children run around on the playing field and the tiles make them shift from one tile to another, shifting their balance, running into each other, and fighting to get the most points and by doing that clearly producing the state of play.

In this case, we tried to make it clear that the players can take multiple roles in the game, and that the actors of the network can be used both with their mental abilities (e.g. competitive revivals) as well as their physical or virtual manifestation (e.g. obstacles or trigger points).

In the following we will go deeper into what the implications of these analyses of games in the view of ANT have for designers of games.

D.9 Design Implications

In the introduction, we stated that games, in our point of view, could be regarded as actors because they function as organizers of other actors. Following Latour, quoted above, games are actors because they make a difference; not because they are human or non-human, social or material. We have tried to show how such "difference" is created when games do something with players. This view represents an understanding of interaction where the subject-object dichotomy is dissolved and agency is distributed in a process of reorganization, recreation and modification of actions in networks that even stretch into the mind and body of the individual player and take advantage of abilities and faculties.

If one accepts this way of viewing, it will have implications for game design, because design is not just a question of creating game worlds and interfaces but also a question of how to design social actors that can take agency and thereby initiate and guide the building of social networks, which can bring human and non-human actors to act together in such a way that the players can achieve an experience they find pleasant, joyful, funny or equivalent. As we have tried to point out, this does not only involve organizing social relations, actions and material, but also requires utilization of the player's abilities, for instance of both physical and cognitive nature.

We believe game design should be done on the basis of knowledge about how human abilities can be organized and influenced including knowledge of the abilities of different user groups. In the analysis, we showed how games orchestrate actions by humans and non-humans and resulted in experiences the players find engaging, joyful, and entertaining. From our point of view that is prototypical examples of what games do. They organize the acting of actors in order to achieve certain kinds of experiences, which, as we have argued, primarily are states of play

Through the inscription, the designer assigns agency in such a way that the game can take advantage of the characteristics of the human players. The games are examples of how the designer renders agency to a non-human object, and how these objects perform a job by getting the players to do a job.

This view gives us a possibility to further investigate how the designer can utilize this understanding when creating games.

Understanding games as active participants in the network created by or around the game, puts emphasis on attributing agency to the game and the elements in it. To understand how this is done, the concept of framing is useful.

Framing is a concept developed by Gregory Bateson [101, 219], who points to the fact that certain situations are perceived differently than we normally would in his essay with the title "This is play" [219] which is now famous both in the context of communication and play research.

The classical example from Bateson is two monkeys playing; where in this framing a bite (an act of attacking) doesn't denote what it normally would (fighting against each other) but is framed in such a way that it is percieved differently. Bateson states, that a bite in the frame of play has to be followed by a metacommunicative signal "this is play", so that the opponent understands it as an act in play and not seriously meant [101, 219]. This is, for instance, the case with computer games such as GTA that we have described earlier. "This is play" puts a frame around every act which signals "not serious". But that does not mean that the acts are without influence on the players. For our viewpoint, this is a tricky point which we have to elaborate on.

The best example is perhaps the feeling of fear. Psychologist and play researcher Michael Apter [104] have put forward the example of meeting a tiger. There is a significant difference between meeting a tiger face to face in the backyard and meeting tiger in a cage, he writes in an attempt to explain that the way we experience our surroundings changes their significance due to the frame we put them into. This is especially true in play. That which outside of play would produce fear, anger and the like, does not produce the same reactions in the framework of play. Still, as the Apter example shows, what we experience in play has to evoke some of the same feelings as reality. If not, we would be bored. A kitten in a cage is not exciting but pittyful. We believe this is a key point in designing games. The "modulation of excitement" of course requires something to modulate. Fear is only one example. Apter writes: "One of the most interesting things about play is the tremendous variety of devices, stratagems and techniques, which people can use to obtain the pleasure of, especially to achieve high arousal [. . .]. Putting aside the use of direct physiological interventions to increase arousal – drugs smoking and drinking – there are a number of general psychological strategies which can be used for this purpose" [104]. A designer must know which emotions, feelings, etc. that produce arousal or other kinds of excitement and joy in the specific target group, and must know how to evoke them in a game. Good designers know that by intuition; however, explicit knowledge may help to make games better or to better avoid failures.

In terms of a game taking agency, the key point is to set the scene for the game; creating a framing where the players are willing to invest time and energy into the game and in the process distributing agency to the game. The players also have to accept the roles and rules of the game. Often this framing is done in the terms of narratives where the designer includes a story that frames the game and divides the roles.

Dividing the roles and hereby building the social network is an important part of the work done by games. This is also the first part of the translation.

We described this in the case of Quackle and how it divided special roles. This is especially clear in GTA and the case of the tiles. In GTA, the social network is built to include the actors of the race but also draw on the bigger picture of why players have to advance through the race. In the case of the tiles, the social network is constructed to create a social awareness of the actors and how they compete and play around with each other.

D.9.1 A word on scripts

The social networks and relations, actions, and materials are not the only elements to take into considerations, The most vital part that the ANT analysis points to, is to take the abilities, feelings and emotions of the players (physical as well as psychological) into account. As described earlier in the inscription, the designer can take advantage of the scripts that the players already have “downloaded”, e.g. the fear of tigers, to mention a simple script.

In the example of Quackle, it was the ability to make the sounds of the animals combined with a common script that made us laugh when we and other people made mistakes inside the frame of play. In the case of the tiles, it was the game structure of “Color Race” where the players had to “catch the color” combined with the script of playful fight. Players know this kind of game; they know how it is played and the designer can use this knowledge.

All these examples are scripts in different types. As described earlier, scripts are a form of manuscripts that we know and which we use to interact and cope with different situations. In a sense, scripts can be seen as a form of recipes.

In that sense, games are dependent on the players. Players have many different scripts and understandings of how to play and what a game is. All these can be seen as part of their play culture. When players play a game or observe others playing, they learn new ways of playing and interacting: new scripts are passed to them.

It’s sometimes easy to see, as when a child looks at elder children playing and starts to mimic their behavior. In this situation the child is starting to “download” the script for their actions and can later reuse these.

In all these small scripts, we have learned that the designers of game are using them in different ways while they are at the same time supplying new ones to the players.

D.10 Conclusion and Future Work

The main theme of this paper has been to establish an understanding of what games do in the perspective of ANT. We have seen how games do an active job and work as what Latour calls a mediator that can "transform, translate, distort, and modify" relations [114]. We believe that ANT is beneficial when we look into computer game design. While it can seem trivial that games do something to users, it is highly important for game designers to understand how games do this and why people are willing to invest time and effort in games.

We have demonstrated that, using ANT as a tool for analysis, can give us a new understanding of the interaction between games and users. We believe that game designers can advance interaction design by "following the actors" and by understanding how agency in games works, and by gaining insight into how certain bodily, psychological, and social acts can create play. We are fully aware that our analysis has shortcomings since it only covers three games although several instances of them and, thus, only a few examples of the kind of actor network which creates play. There are numerous other examples of this kind of network operating in many different ways in games.

Future work should focus on identifying, characterising, and possibly systemizing actor networks in different games. It should also focus on identifying different kinds of key scripts that the designer can utilize and take advantage of. Similarly, it's interesting to further investigate how the understanding of games as translation can help create a better awareness of what is going on in the process of game description.

D.11 Acknowledgment

We would like to thank our colleagues at Center for Playware, the participating children, families and elderly that allowed us to observe their play.

Paper E

Playful Home Training for Falls Prevention - A pilot study using a mechatronical exergame

Abstract — Falling is a big issue among elderly, and prevention of falling is of big importance both for the individual and for society at large. In this paper we present a pilot study with fun exergaming equipment in private homes. The initial findings in the small pilot study suggests that this kind of training makes the elderly train more than they normally do, and they continue to find the training fun for up to 70 training times. Such motivation to train this much is important to understand, since studies of elderly people's barriers to exercises indicate that motivation can be one of the very common barriers. Further, the paper describes how future research within the field will be structured.

Keywords — Elderly, home exercise, exergame, mechatronic, playware.

E.1 Introduction

Falling accidents among elderly inside or outside of their homes is the most common cause of fractures and hospitalization. Falling has many costs of both human and economic and within health prevention training of elderly in order to prevent falls is an important issue. Elderly who are very sedentary have an increased risk of falling. One third of senior citizens 65-80 years of age fall at least once a year [66], while it is half of the population over 80 years of age [220].

Even in a small country like Denmark (5.5 million inhabitants), there are many hospitalizations and high health costs related to falls. Hospitalizations associated with falls in Denmark account for around 13,000 per year in 2005 and are expected to rise to almost 24,000 per year in 2030. 10-20% of the falls result in serious injury, about 5% results in fractures and 1% are hip fractures. Of the people falling 20% die within a year after the incident [32, 72, 220].

Getting elderly to do regular training is essential to avoid falls, since it is known that exercise helps preventing falls in older adults [179, 220]. In recent years a new way of training and rehabilitate called "exergaming" has received increased focus [35]. Exergames are games that require the user to be physically active to play the game, thus the games "...incorporate technology, play, and physical activity..." [35].

While training is essential, we believe it is vital to create the right possibilities for the elderly to train at their own will, and in a fun fashion, so training is considered more of a playful experience. Indeed, motivation of users to a particular desired behavior is an important factor and of high importance for the future state of health. For example, only 5% of the American population has achieved the recommended levels of the general health recommendations, and for diabetes 1/3 of the patients do not follow the prescribed medication [221]. Indeed, notwithstanding the beneficial effects of exercise [222], adherence to lifestyle prescriptions and other more behaviorally demanding regimens including exercise is very low [223, 224], and the effective long-term interventions are labor-intensive and expensive [225, 226]. Studies of elderly people's barriers to exercises indicate that motivation can be one of the very common barriers [227, 228]. Individuals seem to lose their motivation for physical exercise when no longer intensely monitored or coached. Knowledge of the health benefits of physical activity does not in itself insure motivation.

Both physical and cognitive training is primarily based upon repetitive exercises and are dependent on the users being motivated continuously. Working with motivation is a central part of health workers' tasks. For novel welfare products, which aim at having the individual citizen to take care of her own health, and individually take care of prevention and rehabilitation, it is of paramount importance to be able to motivate the users [221]. This demands a design of interaction between technology and users based upon knowledge on what motivates users, e.g. users who rehabilitate in their own home.

In former work with exergaming for elderly, we have showed that training with the Interactive Modular Tiles (IMT) have the possibilities of enhancing the participants physical abilities [2]. Our earlier intervention have been in the context of municipality run "day centers" in Denmark, which are activity centers for elderly where they come to do different activities. In that test, participants would not train more than once a week in the activity centers, while the official guidelines in Denmark is at least 30 min of activity every day [229].

In this paper, we will present our pilot work with exergaming in the context of private homes, where the goal has been to see if it is possible for elderly 70+ years of age to train a few times a week and if they will find this kind of training motivating. We will also look into how we can structure future bigger tests to obtain the optimal effect of the training.

E.2 Playware, Exergaming and IMT

The development of the mechatronical system for playful home training finds its foundation in the combination between playware research, exergaming, and modular interactive technology inspired by modular robotics and modern artificial intelligence.

E.2.1 Playware

Playware is intelligent hardware and software that creates play and playful experiences for users of all ages [2, 29]. Playware-tools are tools with a "behavior" that initiates play (e.g. a motion, in the case of sensorimotor play) via interaction. Play is here understood as what we normally sees as playful behavior, which is defined as a volunteer activity, done for its own sake and for the fun of it. Thus, play is a state of being, different from other states of being, and something humans (of all ages) like to do [96]. To bring us into the state of play we need tools, be it physical or non-physical. These "play tools" is the basis for what is labeled "play dynamic" through which the users are brought into a state of playing. A simple example is play of dizziness where the player is spinning around and thus bringing the body into a special mood - a state of play. R&D in playware has led to numerous applications in various areas such as rehabilitation, playgrounds, education, art, and sport. In all such cases, users interact with the playware as a free and voluntary activity that they engage in for the pleasure of play, even if the activity may be shown to have collateral effects e.g. in terms of health and skills. Indeed, play is suitable for health promotion as it intrinsically can motivate to activity by its open-ended and continuously formed (e.g., curiosity) nature, and its ability to evolve in social interaction, afforded and mediated by situational and technological conditions.

Modular playware has been proposed as of particular interest to develop solutions for such varied areas of application, since modularity may facilitate easy assembly and adaptation of the playware to different interaction modalities [19].

We can outline several guidelines for the design and development of modular playware [19], which should help in the designing playware that acts as play dynamic. Important features of this design approach are modularity, flexibility, and construction, tangible interaction and immediate feedback to stimulate engagement, activity design by end-users, and creative exploration of play activities. These features permit the use of such modular playware by many users, including older adults who often could be prevented from using and taking benefits from modern technologies. The objective is to get anybody moving, exchanging, experimenting and having fun, regardless of their cognitive/physical ability levels.

E.2.2 Exergaming

Exergaming can be viewed as a subset of playware. Exergames incorporates technology, play and physical activity and are also referred to as exertion games, exertainment, active-play video games, interactive computer games or game-based technology-mediated physical activity. Exergames are video games with interfaces that require active involvement and the exertion of physical force by participants. They are designed to track body motion and provide both fun and exercise for game players [35].

Some of the better known exergames are Nintendo Wii, Dance Dance Revolution (DDR), Playstation 2 EyeToys games and Microsoft Kinect games. As mechatronic systems, exergames combine the game control with use of different types of sensors and inputs that require the players to be active to play and win the games, e.g. balance boards, dance pads, gym equipment, cameras, remote controls with accelerometers and heart rate monitors. Thus, exergaming relies on mechatronics for tracking body movement or reaction.

There has been increasing interest in exergaming over the last decade [39]. As Larsen et al. [35] outline, most exergaming studies have been performed with young users, and so far there is limited evidence of the effect of exergaming among older adults. Nevertheless, the systematic review on the physical effect of exergames in healthy elderly by Larsen et al. [35] demonstrates that exergames have potential for improving physical health in elderly. At the same time, however, the review shows that there is a clear need for additional and better-designed studies assessing the effectiveness and long-term adherence of exergames designed specific to elderly. It is contemplated that the beneficial effect of exergaming on motivation and enjoyment of exercise may be due to initial increase of motivation. Therefore, the systematic review concludes that studies are needed to reveal if adherence to exergaming persist over time. As a consequence, in this paper we will set up and investigate an intervention with 45-70 sessions of exergaming.

E.2.3 IMT

The mechatronic system of modular interactive tiles is a playware developed as an exergaming system inspired by modular robotics and embodied artificial intelligence. The embodied artificial intelligence approach promotes an understanding of the relationship and interplay between the body (hardware) and the brain (software), and we can facilitate the development of embodied artificial intelligence mechatronical systems with the modular approach of modular robotics. The modular robotics manifests distributed, parallel processing in a physical form. We have explored this general concept of interactive, distributed parallel processing in a physical form since the mid-1990s and developed several physical platforms in order to test the concept in different use contexts. Generally, the concept can be used to create self-reconfigurable modular robots [230], which autonomously change their physical shape, which we did in the 2000's, but here we will focus on how the concept can be used to create user-configurable modular interactive systems, specifically in the form of modular interactive tiles.

We started to investigate exergaming in the form of mechatronic systems in 2001 with Europe's largest producer of playgrounds, KOMPAN, engaging in the development of interactive electronic playgrounds [29]. Initially, sensors and actuators were distributed on traditional playground products (see Figure E.1 left), later wire-connected modular tiles were developed as the ground of playgrounds (see Figure E.1 right), and finally the ICONS product emerged on the market. The playground tiles became an implementation used for several studies of children's physical interactivity and of adaptation to the individual user.

Despite the relative success of the playground experiments, we wanted to push towards a more free use of modules. Some of the playground work was based on wired connection between modules, which essentially limited the reconfiguration of modules to be performed by the installation worker, and not to be performed by the user. Certainly, for a future use as an exergame for older adults' training in their private homes, such a wired mechatronic system would pose serious challenges.

Therefore, we developed the modular interactive tiles. Each tile is a self-contained module with processing power and communication to neighboring modules, and a number of these can be put together in any physical shape by the user within a minute. The tiles light up in different colors and can perceive the pressure when people press them with their hands or jump on them with their feet. Numerous games (exercises) are running on the tiles, and these games aim at providing high motivation for people to engage physically with the tiles.

Each modular interactive tile has a quadratic shape measuring 300mm*300mm*33mm – see Figure E.2 and Table E.1. It is moulded in polyurethane. Inside, the printed circuit board (PCB) has the electronic components mounted, including an ATmega 1280 as the main processor in each tile. At the center of each of the four sides of the quadratic shape infra-red (IR) signals can be emitted and received (from neighboring tiles). Each side of a tile is made as a jigsaw puzzle pattern to provide opportunities for the tiles to attach to each other. The cover is made from transparent satinice.

Figure E.1: Examples of mechatronic playgrounds. Left: sensors and actuators on a traditional playground product. Right: wire-connected, interactive tiles as floor surface for playgrounds.

A force sensitive resistor (FSR) is mounted as a sensor allowing analogue measurement on the force exerted on the top of the cover, and there is a 2 axis accelerometer to detect horizontal or vertical placement of the tile. Eight RGB light emitting diodes are mounted with equal spacing in between each other so they can light up underneath the transparent satinice in a circle.

The modular interactive tiles are individually battery powered with a rechargeable Li-Io polymer battery, which can run continuously for approximately 30 hours and takes 3 hours to recharge – an important long battery life for bringing a tile set around to private homes and to be used for long time without the need to

Figure E.2: Modular tiles used for feet or hand interaction.

perform recharging.

The tiles' printed circuit board has connectors to mount an XBee radio communication add-on PCB, including the MaxStream XBee radio communication chip. Hence, there are two types of tiles, those with a radio communication chip (master tiles) and those without (slave tiles). The master tile may communicate with the game selector box (an RFID reader that reads RFID game cards) and initiates the games on the built platform. Every platform has to have at least one master tile if communication is needed e.g. to game selector box or a PC.

With these specifications, a system composed of modular interactive tiles is a fully distributed system, where each tile contains processing (ATmega 1280), own

Table E.1: SPECIFICATION OF A MODULAR INTERACTIVE TILE.

	Amount	Type
Processor	1	ATmega1280
Sensor	1	FSR
Sensor	1	2-axis accelerometer
Effector	8	RGB colour LEDs
Communication	4	IR transceivers
Communication	1	XBee radio chip
Energy	1	Li-Io Polymer battery
Switch	1	On/Off switch
Connector	4	Jigsaw puzzle
Size	300mm*300mm*33mm	
Weight	1 kg	

energy source (Li-Io polymer battery), sensors (FSR sensor and 2-axis accelerometer), effectors (8 colour LEDs), and communication (IR transceivers, and possibly XBee radio chip). The modular interactive tiles can easily be set up within one minute. The modular interactive tiles can simply attach to each other as a jigsaw puzzle, and there are no wires. There are numerous games for both physical and cognitive training.

E.3 Method

The intervention has been structured as a pilot study, where the goal was to investigate how we can use the IMT in private homes of older adults to ensure that the participants got enough daily training to secure they keep their physical abilities at a level where they are at a very small risk of falling.

The intervention was divided into two parts. The first was an exploratory study, where the IMT was placed in two private homes after careful instruction by one of the authors, on how to use them and the expectations of the users. In this first part, the users were able to use the tiles as they wanted. The possibilities the participants could chose from was (i) what games to play, (ii) the amount of time used and (iii) how often they wanted to play (we asked them to try and train around 3 times a week, but they were also free to train more). The second part was a more structured session, where the participants were presented with a poster telling them what games to play and for how long (see Figure E.3). They were asked to play two minutes (using a count-down timer) of each game and do all the games two times.

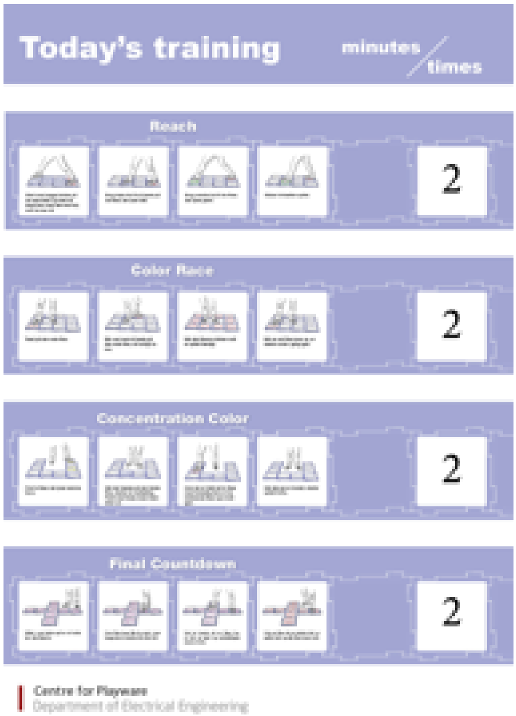

Figure E.3: Poster of training for section part of intervention.

The organization of these two structures (first open then closed training program) was done in order to allow for a open dialog of any general problems with the IMT as a private training system, before setting up a specific order of training. The specific training schedule was setup after observing and doing informal interviews with the participants to see how they used them in this setting. This also allowed us to get their views on the two types of structures.

Once a week, the participants were observed while using the tiles. Here the participants had the opportunity to ask questions and the observer where able to talk with the participants about their use of the tiles (informal interviews). At these observations and the amount of play time on the IMT was also registered (see Table E.2).

After the intervention, which lasted for 7 weeks for the first participant and 6 weeks for the other, a semi-structured interview was preformed with the two participants [158].

E.3.1 Participants

Participant number one (P1) was an 84 year old woman. She did not have severe balancing issues but indicated that she had some problems with balance. After the intervention was initiated (2 days into the project) she was diagnosed with arteriosclerosis and an angioplasty was scheduled after the intervention ended. As this was a pilot study, we did not exclude the participant, but this might have had an influence on her experience of the project. She was going to a physiotherapist for training of an arm. She was used to swimming a lot, but she was unable to do much of this after the discovered arteriosclerosis.

Participant number two (P2) was 79 years old and was unable to walk without a cane. She had a hip replacement six month earlier. She was still unable to recover fully from the surgery and this was also part of her reason to join the pilot. She did exercises everyday that she was instructed about by the physiotherapist, she had also added some extra exercises that she had been taught elsewhere. Regularly, she went to a gym with a physiotherapist attached. In general she did not do much walking outside, as she was unable to walk without the cane.

E.4 Results

The two interventions were ended with a semi-structured interview in order to collect data about how this kind of technology was perceived by the participants. Along with the observations (some video-recorded) and the time measures of the playing time at the observation, these are the results from the project, which will be presented and afterwards discussed for learning's to be used in next phase where are larger study is planned.

In Table E.2, the average training time for each game at each session is presented along with the overall training time. While we did not measure the training at the times they trained alone, the participants indicated that this was equal to what they did on their own.

Both participants indicated that they had trained every day in the period they were involved in the project (P1 had two days of not training, where she was admitted to the hospital).

In average the participant trained for 18.5 and 17 minutes every time. This is a bit higher than what we have seen in earlier studies with the IMT, where the participants trained for 10-15 minutes [2]. P2 trained two times a day with a total training time of 34 minutes while P1 only trained once a day for 18.5 minutes. P1 had a total of 45 training sessions, while P2 had 70 training sessions.

Table E.2: TRAINING TIME AT VISITS

Game	Average min. pr. session	
	Participant 1	Participant 2
Reach	6	4
Concentration Color	5	4
Color Race	3.5	2.5
Simon Says	3	6
Final Count Down	1	0.5
Total training time	18.5	17

In the interview with the participants the following was stated quotes are translated from Danish:

They both enjoyed the training with the IMT compared to regular training. One indicated that the normal training was a “drag to do”. They felt there was some competition in it: “Can I remember the colors in the game, can I manage to press the tile before the time is out.”, “Can I press 30 tiles in 30 seconds.” (for explanations see Figure E.3).

P1 one indicated that she was starting to get bored with the same games, while P2 was still having fun with them. They both felt it could be interesting after a while to get new games, and they also liked the idea of having a break from this form of training to resume it again on a later point.

P2 also indicated that she used the IMT training as a carrot after she finished the training her physiotherapist had ordered.

They both found it easy to use the IMT, but turning them on (where they had to get down to the floor to do it), was kind of hard and annoying. P2 had experienced a few bugs, but she was able to figure them out by herself with no problems.

P2 stated that she had begun to walk more around. As an example it used to be her boyfriend that went to the shop to buy a newspaper, but the last few weeks she had been going with him (the distance is about 1 km), which was something she was very happy about. She also told that visitors had noticed she was moving around and doing stuff much faster than she used to do: "They think that I can do more than I used to."

In regards to the two ways of training, with or without the poster of games to play, P1 was very enthusiastic about the paper and the structure it provided: “”Very good... Then you have something focused to go after also for a limited time.”. While P2 liked it, but thought she might be training a bit less than before.

They would not mind having more games on the poster, but they also indicated that it in some way limited the fun, as they could not just play what they wanted to do.

From the observations and informal interviews it also became obvious that the games with a clear and meaningful goal was the ones the preferred to play. Especially games which demanded some sort of use of the memory was the favorite games.

E.5 Discussion

The results of the pilot study presented here can be seen in the light of 'patients at home', a concept that tries to bring patient treatment and interaction to the private home of the patient. The need to make citizens more self-reliant and more engaged in healthy activities in everyday life is urgent, if we are to cope with the increasing demographic pressure put on our health care systems. Technology is increasingly recognized as a means by which to involve patients and citizens more directly in their own care, e.g. via telemedicine.

However, there are serious challenges in relying on patients taking care of their own rehabilitative exercises in their own homes. Adherence to exercise is generally very low, and the effective long-term interventions are labor-intensive and expensive. Individuals seem to lose their motivation for physical exercise when no longer intensely monitored or coached. Since knowledge of the health benefits of physical activity does not in itself insure motivation, other means than promoting health knowledge is needed.

In this light, the results of the present pilot study are both interesting and encouraging, as they indicate that it may be possible to motivate older adults to adhere to intensive physical exercises over a long time with many exercise sessions. With the self-chosen high adherence and intensity of training by the participants, it is indicated that they were intrinsically motivated to perform the exercises for their own enjoyment.

As such we will consider that the pilot study of using the exergaming device IMT in private homes for elderly with balancing problems have given indications that this type of training is worth going more into depth with. In this section we will discuss the findings and how they translate in to a larger effect study for the same target group.

The participants used more time on this training than we had originally thought possible. As such they trained every day and for 17-18 minutes at a time. One even trained two times, making the training reach the recommended time of 30 minutes a day. This indicated that the possibility of training at their own will in the time they find suitable, allows for much more training time than first believed, and as such securing that the participants get closer to the recommended exercising time (30 minutes).

If we look at the motivational element, then we see that the participant played the same games 45-70 times and still was only starting to lose motivation. This indicates that there is indeed a maximum of time the same game can be played, but also that these games might last longer than initially perceived.

Also the amount of sessions the participant played indicates that was 45 and 70, and only P1 indicated that she was starting to get a bit tired of the same games every time. They both agreed that the training on the IMT was more fun than normal training and some kind of progress was detected, though this was not the main objectives and too many unknown exist for us to know if this was indeed the case that the IMT assisted with this or not.

E.6 Future work

In the pilot we saw that the users are able to play the same games for up to 70 times without problems of losing motivation. Therefore we have planed the next study to be with a fixed amount of games for four weeks, and with training everyday as this have proven to be possible.

We will also collect data to see if any progress can be observed from before to after the intervention in same way as we have seen in earlier studies [2]. Such previous studies showed that community-dwelling elderly could obtain statistical significant improvement in functional abilities including balancing, strength, mobility, agility and endurance after short term training with the IMT in social settings (i.e. group training in elderly activity centers). Collecting similar pre- and posttest data from in-home training could then compare to progress with other exercise methods for prevention of falls in older adults, where recent randomised controlled studies show that exercise appears to be a useful tool in fall prevention in older adults, significantly reducing the incidence of falls compared with control groups [231].

For securing enough training without having a too rigid structure we will create a poster of games to play, but not set a fixed time for them, and instead just measure the time they spend on each game (using a stop watch).

As part of the testing, it should be tried to establish a control group, but for ethical reasons a so called “cross-over” design will be used. This is a design where one group is control and the other intervention, but after the four weeks they switch, so the control group becomes intervention and likewise. This will also allow for getting a view on how participants react to having trained for fours weeks and then not training for the next four weeks.

E.7 Acknowledgment

We would like to thank the two participants in the project for allowing us to come into their homes and do an experiment with home training, and for using time to give us feedback on the experience and any shortcomings and good suggestions.

We would also like to thank our colleagues at Center for Playware for feedback and good advices,

Paper F

Study protocol: Effect of Playful Training on Functional Abilities of Older Adults - A Randomized Controlled Trial

F.1 Abstract

Background: Loss of functional capabilities due to inactivity is one of the most common reasons for fall accidents, and it has been well established that loss of capabilities can be effectively reduced by physical activity. Pilot studies indicate a possible improvement in functional abilities of community dwelling elderly as a result of short-term playing with an exergame system in the form of interactive modular tiles. Such playful training may be motivational to perform and viewed by the subjects to offer life-fulfilling quality, while providing improvement in physical abilities, e.g. related to prevent fall accidents. The RCT will test for a variety of health parameters of community-dwelling elderly playing on interactive modular tiles. **Methods:** The study will be a single blinded, randomized controlled trial with 60 community-dwelling adults 70+ years. The trial will consist an intervention group of 30 participants training with the interactive modular tiles, and a control group of 30 participants that will receive the usual care provided to non-patient elderly. The intervention period will be 12 weeks. The intervention group will perform group training (4-5 individuals for 1h training session with each participant receiving 13 minutes training) on the interactive tiles twice a week. Follow-up tests include 6-Minute Walk Test (6MWT), the 8-foot Timed Up & Go Test (TUG), and the Chair-Stand Test (CS) from the Senior Fitness Test, along with balancing tests (static test on Wii Board and Line Walk test). Secondary outcomes related to adherence, motivation, and acceptability will be investigated through semi-structured interviews. Data will be collected from pre- and post-tests. Data will be analyzed for statistically significant differences by checking that there is a Gaussian distribution and then using paired t-test, otherwise using Wilcoxon signed-rank test. "Intention to treat" analysis will be done. **Discussion:** The trial tests for increased mobility, agility, balancing, and general fitness of community-dwelling elderly as a result of playing, in this case on modular interactive tiles. A positive outcome may help preventing loss of functional capabilities due to inactivity. **Trial registration:** ClinicalTrials.gov: Nr. NCT02496702, Initial Release date 7/7–2015.

Keywords: exergaming, play, functional abilities, falls prevention.

F.2 Background

This protocol works with three main concepts: - Playware: defined as "Intelligent hard- and software that creates playful experiences for people of all ages."[6].

- Exergames: games that require the user to be physically active to play the game, thus the games "... incorporate technology, play, and physical activity..." [35]. These are a subset of playware.

- Interactive modular tiles (IMT): The product used in this project, which are developed at Center for Playware and are used to create exergaming and play [18].

These concepts are used with elderly citizens in interventions, which should be playful and motivational to perform, in order to prevent loss of functional capabilities and related falls.

Fall accidents among elderly inside or outside of their homes is the most common cause of fractures and hospitalization. Falling has many human and economic costs and within health prevention training of elderly in order to prevent falls is an important issue. Elderly who are very sedentary have an increased risk of falling. One third of senior citizens age 65-80 fall at least once a year [66], while it is half of the population over 80 [220]. Hospitalizations associated with falls in Denmark account for about 13,000 per year in 2005 and are expected to rise to almost 24,000 per year in 2030. 10-20% of the falls result in serious injury, about 5% results in fractures and 1% are hip fractures. Of the people falling 20% die within a year after the incident [66, 72, 32].

Loss of functional capabilities due to inactivity is one of the most common reasons for falling, and it has been well established that loss of capabilities can be effectively reduced by physical activity [67, 35]. Research has also shown that barriers for elderly being physically active include poor health, fear of injury or lack of motivation, opportunities or companionship.

Because of the magnitude of problems associated with falls this is an area of big interest. A recent Cochrane review on "Interventions for preventing falls in older people living in the community (Review)" [66] showed that 159 randomized controlled trials (RCT) have been reported with interventions aimed at preventing falls among adults 60+. The 159 trials had a total of 79,193 participants. 59 of these trials (13,264 randomized participants) tested the effect of exercise on falls [66].

While prevention of falling is a well researched area with indications that exercise can significantly reduce rate of falls and risk of falling [66], the outcome of single category programmes are lacking evidence:

"Other than for Tai Chi, there was no evidence that single category programmes were effective, for example balance retraining or muscle strengthening exercises alone." [66].

Likewise there has been performed little research of this kind in the area of exergames as a tool to perform such exercises [35].

In the review of the area, Larsen et al. [35] found seven studies of RCT's of exergames. While the review indicate overall positive effect of exergames (6 out of 7 have positive effect) there is still lack of evidence on the use of exergames as an effective intervention for elderly people as a means against falls. The goal of this project is to investigate and validate the use of one type of exergaming training tool (the IMT) to prevent loss of function and decrease chance of falls among elderly people. The project will compare training with the IMT to usual care in the field with the aim of investigating whether the playing element will result in an improved physical progress compared to usual care.

In 2012 a pilot study of the use of the IMT in municipalities with no control group was conducted. This initial pilot study in Gentofte municipality in Denmark showed that the use of playware technology for training and play can provide statistically significant progress in several of the parameters used to measure the risk of falls among the elderly. The pilot study in Gentofte municipality with 16 participants showed that there is significant improvement in the balance (65%), endurance (6 minute walking test) (26%), strength in the lower body/chair stand (20%) and dynamic balance and agility (Timed Up and Go) (18%) after just ten training times of 12-15 minutes per. time. In addition to the physical benefits, it was highlighted in subsequent interviews that it was fun to work out on the tiles, and 80% wanted to continue with this kind of playful training [32].

The indications from this pilot study and a MAST [131] investigation of the playware technology have indicated the need for a RCT study to validate both the technology and play as a motivation for exercises among elderly to prevent loss of functionality and falls.

The IMT is a distributed system consisting of individual functional digital tiles. These tiles are designed as puzzle pieces and can be assembled and dissembled in a matter of minutes. The tiles are able to sense pressure and light up in a rainbow of different colors.

Using the many different colors and the pressure sensor a variety of different games have been created where the player must move around and step on the different tiles, and thus making the user move as part of playing on the tiles [18, 2].

F.3 Methods/Design

F.3.1 Objectives

The research hypothesis is that playful training here in the form of the IMT, will make participant perform better on the follow-up tests (6-Minute Walk Test (6MWT), the 8-foot Timed Up & Go Test (TUG), and the Chair-Stand Test (CS) from the Senior Fitness Test [30], than participants not using the IMT. Further it is expected that the participant will perform better on balancing tests (static test on Wii Board and Line Walk test), have a high degree of adherence (participation in +90% of the training), express that IMT is motivating for the training and IMT have a high acceptability.

F.3.2 Trial design

This study will investigate the use of one form of exergames called IMT, and how this compares to usual care of elderly people 70+. The trial will consist of two groups, one for training with the IMT and one group for usual care that will receive the care provided to non-patients elderly, which at this moment is no additional treatment other than recommendations.

The study will be a single blinded, randomized controlled trial. The study will be funded by the patient@home project, and equipment by Entertainment Robotics. Concealed allocation and intention-to-treat analysis will be used. Measurements will be taken at baseline and after intervention. Upon acceptance the protocol will be registered in clinicaltrials.gov.

The trial's results will be reported using domains and categories described in the taxonomy developed by the Prevention of Falls Network Europe, to allow future synthesis of evidence, or study replication [232].

F.3.3 Study settings

In Denmark, care for the elderly by the municipalities consists of many different services. Care is given in form of nursing homes, day centers and care at the private homes depending on the elderly and their abilities. The care is granted by the municipalities, and is an ongoing negotiation on the amount of money for elderly care and other services provided by the municipalities.

Activities for elderly consist of volunteer activities such as gymnastics (local teams often with public support), day centers where elderly is screened and appointed to, or rehabilitation normally after operations or hospitalization. In a recent study [2], elderly at a day center participated in exercising with playware technology.

In this study, the participants will be participating in training at facilities appointed by the participating municipalities. The intervention will consist of two weekly group training sessions for the participants.

The interventions group will train using interactive modular tiles. The tiles include preprogrammed games that create playful training for the participants. The tiles are described in Lund [18], and Lund and Jessen [2].

The control group will receive “usual care”, which here refers to normal day activities.

The intervention is done in the form of groups of 4-5 participants per set of tiles, with 2-3 sets of tiles at a time. As more sets can be used it is possible to make groups of more people. The training will consist of 1.5-3 minutes of training (depending on the game) on tiles and then rest while the other 2-3 participants train (4-6 minutes of break). Then the participants will train for 1.5-3 minutes again until each participant has received a total of 13 minutes of training. The control group will not train.

F.3.4 Inclusion criteria

Community-dwelling men and women aged 70 and above will be included in the project. As the project is a preventive study there is no special requirements to the participants other than the above.

F.3.5 Exclusion criteria

Participants will be excluded if any of the following are identified:

- A previous diagnosis of strong dementia or a cognitive decline that prevents the understanding of simple instructions or guidelines;

- A previous stroke with a severe neurological impairment, such as loss of strength, and perceptual or language limitations;

- A severe visual deficiency;

- Inability to maintain a standing position, even with the use of a walking aid or other device;

- Participating in rehabilitative training.

F.3.6 Primary outcome

The primary outcome measures using pre- and posttests of the TUG, 6MWT and CS. The tests 6MWT, TUG and CS are described in the Senior Fitness Tests Manual [30]. The Senior Fitness Test [30] score fitness standards (performance cut points) that are associated with older adults ability to function independently. More than 2000 older adults have been scored, and the cut points' accuracy and consistency have been validated as clear predictors of physical independence. The test can classify each individual into one of four levels (above average, normal range, below average, or low functioning) and can be used to assess the individual's health risk level.

Three different tests from the Senior Fitness Test [30] are focusing on health risk prevention, such as mobility, agility, balancing, and general fitness, and are well established for testing a variety of health parameters in community-dwelling elderly. These tests include the 6MWT, the 8-foot TUG, and the CS.

Studies have shown that the 6MWT can be used as a fall risk indicator specifically for frail elderly [167]. Furthermore, the 6MWT not only measures aerobic fitness and mobility, but also incorporates components of leg strength, balance, reaction time, and vision.

It has been shown that the TUG reflects a combination of sensory, motor, and strength abilities [168] and can be used as a measurement of functional mobility [87]. It has also been shown that the TUG can be a tool for discriminating between future fallers and nonfallers [167]. It has been demonstrated that the 8-foot version of TUG have similar qualities for agility and dynamic balancing and that this test is a reliable test for predicting future fallers and nonfallers from among the community-dwelling elderly population [169]. The CS measures lower body strength and endurance and the CS has been shown that the CS is a reliable and valid indicator of lower body strength in generally active, community-dwelling older adults [170].

F.3.7 Secondary outcomes

The following secondary outcomes will also be collected as part of the intervention:

- Line Walk test which is a test to measure balance.

- Static Balance will be measured using Wii Balance Board, which have proven to be a valid measure of balance [174]. This measure will be done using an application developed by Francesco Sgró and colleagues [174].

- Adherence to training

- Motivation for training

- Acceptability of IMT

Adherence to the training will be measured by registering the number of times the participants participate and how much they participate at each session. Semi-structured interviews will be done with the participant after the intervention to investigate motivation and acceptability of the IMT.

F.3.8 Sample size/power analysis

The data from the pilot study (described in Lund and Jessen [2]) was used to do a power calculation. The results showed that for a power of 80 there is a need for 20 persons in each group. As the population of community-dwelling elderly is expected to exhibit a high variance in functional abilities (higher than the population of the pilot study) we have increased the number of participants to 30 in each group. This also allows for dropouts from the study, which we experienced before initializing the pilot study.

F.3.9 Statistical methods

F.3.9.1 Primary outcome analysis

Data will be collected from pre- and post-tests. Data will be analyzed for statistically significant differences by first checking that there is a Gaussian distribution and the using paired t-test, otherwise using Wilcoxon signed-rank test. The Wilcoxon Signed-Rank Test is selected because the population of community-dwelling elderly is expected to exhibit a high variance in functional abilities. Therefore a normal distribution of the population's test scores cannot be assumed. The Wilcoxon Signed-Rank Test is a statistical hypothesis test suitable under such circumstances.

"Intention to treat" analysis will be done. These two conditions (ie, all participants, as randomized) are widely recommended as the preferred analysis strategy.

F.3.9.2 Secondary outcome analysis

Data from the LW test will be calculated in the same way as the primary outcomes. Adherence will be calculated for the average and standard deviation for the participant. This will be compared to a goal of minimum 90% adherence to training.

Motivation will be based on the average scores and standard deviation from the participant interviews (questionnaire on motivation) as will the acceptability.

F.4 Discussion

Investigating if short-term playful training on the IMT will increase mobility, agility, balancing, and general fitness of community-dwelling elderly is the goal of the study. A positive result may help creating more training opportunities to help prevent loss of functional capabilities due to inactivity.

The study has several logistic challenges, as the participants are living at home but most have balancing problems, which prevent them from getting to a training facility on their own. This have been sought dealt with by going into a cooperation with two Danish care-centers, where elderly come one or two times a week to do different activities (arts and social activities mainly). This means that it could be argued that the participants of the study is only a subset of the elderly in general, but this subset is fairly representative for the municipality.

F.5 Competing interests

JDJ declares no competing financial interests exist.

HHL is a director of the Entertainment Robotics company, which produced the modular interactive tiles.

F.6 Authors' contributions

Jari Due Jessen (JDJ) and Henrik Hautop Lund (HHL) conceived of the project and are leading the project. JDJ wrote the protocol and will implement it. HHL will supervise the project strictly on the academic content as a PhD supervisor for JDJ. HHL has no decision-making authority over the project.

Falck Health/Lasse Holm-Hansen will perform the physical assessments of the participants before and after the intervention.

Jonas Nyvold Pedersen has done power analysis and will do statistical analysis of the data after the intervention.

Paper G

Complete study protocol: Protocol for test of Interactive Modular Tiles

G.1 Title

G.1.1 Scientific title

Efficacy of Interactive Modular Tiles training versus "usual care" on physical attributes among elder adults 70+. A randomized controlled trial.

G.1.2 Public title

Playware technology for balance training. A randomized controlled trial.

G.2 Trial registration

G.2.1 Trial identifier and registry name

The trial will upon ethical approval be registered on clinicalTrials.gov.

G.2.2 WHO Trial registration Data Set

The WHO data set can be seen in figure G.1

Data category	Information
1. Primary Registry and Trial Identifying Number	Clinicaltrials.gov – Nr. NCT02496702
2. Date of Registration in Primary Registry	Initial Release date 7/7–2015
3. Secondary Identifying Numbers	VEK: H-15006703
4. Source(s) of Monetary or Material Support	Danish Council for Strategic Research and the Danish Council for Technology and Innovation (through Patient@home project) Entertainment Robotics (tiles)
5. Primary Sponsor	Danish Council for Strategic Research and the Danish Council for Technology and Innovation
6. Secondary Sponsor(s)	Technical University of Denmark
7. Contact for Public Queries	Jari Due Jessen, Center for Playware, Technical University of Denmark, mail: jdje@elektro.dtu.dk, phone: +45 31182137
8. Contact for Scientific Queries	Jari Due Jessen, Center for Playware, Technical University of Denmark, mail: jdje@elektro.dtu.dk, phone: +45 31182137
9. Public Title	Playware technology for balance training. A randomized controlled trial.
10. Scientific Title	Efficacy of Interactive Modular Tiles training versus “usual care” on physical attributes among elder adults 70+. A randomized controlled trial.
11. Countries of Recruitment	Denmark
12. Health Condition(s) or Problem(s) Studied	Balance and physical health of elderly (70+ years old)
13. Intervention(s)	Playful training on Modular Interactive Tiles (Playware)
14. Key Inclusion and Exclusion Criteria	Inclusion criteria: 70+ years old, with a history of falls, community dwelling. Exclusion criteria: A previous diagnosis of dementia or a cognitive decline that prevents the understanding of simple instructions or guidelines; A previous stroke with a severe neurological impairment, such as loss of strength, and perceptual or language limitations; A severe visual deficiency; Inability to maintain a standing position, even with the use of a walking aid or other device; Participating in rehabilitative training.
15. Study Type	Randomized controlled, assessor and data analyst blinded, parallel-group, superior.
16. Date of First Enrollment	12. January 2016
17. Target Sample Size	60 participants, 30 in interventions, 30 in control group.
18. Primary Outcome(s)	Physical attributes (scores in Senior Fitness Test: Timed Up and Go, 6 Min Walking Test, Chair Stand)
19. Recruitment Status	Recruitment finished (29. January 2016)
20. Key Secondary Outcomes	Static balance (using a Wii Board), Line Walk test, adherence to training, motivation and acceptability of IMT

Figure G.1: WHO Trial Registration Data Set.

G.3 Protocol version

Version number: 1.4
Issue date: 05. February 2016
Protocol amendment number: 4
Authors: JDJ
Revision chronology

G.4 Funding

Initiator to the project is the patient@home project (www.patientathome.dk/en) and Center for Playware (www.playware.dk) who support the project with a total of 2.5 million dkr.

Entertainment Robotics (www.e-robot.dk) is supporting the project with equipment in the form of Interactive Modular Tiles.

G.5 Roles and responsibilities

G.5.1 Contributions

Jari Due Jessen (JDJ) and Henrik Hautop Lund (HHL) conceived of the project and are leading the project. JDJ wrote the protocol and will implement it. HHL will supervise the project strictly on the academic content as a PhD supervisor for JDJ. HHL have no decision-making authority over the project.

Falck Health/Lasse Holm-Hansen will perform the physical assessments of the participants before and after the intervention.

Jonas Nyvold Pedersen has done power analysis and will do statistical analysis of the data after the intervention.

G.5.2 Trial sponsor contact information

Trial sponsor: Technical University of Denmark
Sponsors refence: 55876-phd1
Contact name: Jari Due Jessen
Address: Elektrovej building 326, room 110, 2800 Kgs. Lyngby

Telephone: +45 3118 2137
Email: jdje@elektro.dtu.dk

G.6 Background and rationale

G.6.1 Area concepts

In this protocol we are working with three main concepts that we here briefly will explain. Playware: Playware is defined as "Intelligent hard- and software that creates playful experiences for people of all ages." [6].

Exergames: Exergames are games that require the user to be physically active to play the game, thus the games "...incorporate technology, play, and physical activity..." [35]. These are a subset of playware.

IMT: These are the concrete product used in this project, which are developed at Center for Playware and is used to create exergaming and play [18]. See figure G.2 for technical data.

Description	*Amount*	*Type*
Processor	1	ATmega1280
Sensor	1	FSR
Sensor	1	Two-axis accelerometer
Effector	8	RGB color LEDs
Communication	4	IR transceivers
Communication	1	XBee radio chip
Energy	1	Li-Io polymer battery
Switch	1	On/off switch
Connector	4	Jigsaw puzzle
Size	300 × 300 × 33 mm	
Weight	1 kg	

IR, infrared; LED, light-emitting diode.

Figure G.2: Technical description of the IMT.

G.6.2 Background

Falling accidents among elderly inside or outside of their homes is the most common cause of fractures and hospitalization. Falling has many human and economic costs and within health prevention training of elderly in order to prevent falls is an important issue. Elderly who are very sedentary have an increased risk of falling. One third of senior citizens 65-80 fall at least once a year [66], while it is half of the population over 80 [68, 69, 70]. Hospitalizations associated with falls in Denmark account for about 13,000 per year in 2005 and are expected to rise to almost 24,000 per year in 2030. 10-20% of the falls result in serious injury, about 5% results in fractures and 1% are hip fractures. Of the people falling 20% die within a year after the incident [72, 71].

Loss of functional capabilities due to inactivity is one of the most common reasons for falling, and it has been well established that loss of capabilities can be effectively reduced by physical activity [67, 35]. Research has also shown that barriers for elderly being physically active include poor health, fear of injury or lack of motivation, opportunities or companionship.

Because of the magnitude of problems associated with falls this is an area of big interest. A recent Cochrane review on “Interventions for preventing falls in older people living in the community (Review)” [66] showed that 159 randomized controlled trials (RCT) have been reported with interventions aimed at preventing falls among adults 60+. The 159 trials had a total of 79,193 participants. 59 of these trials (13,264 randomized participants) tested the effect of exercise on falls [66].

While prevention of falling is a well researched area with indications that exercise can significantly reduce rate of falls and risk of falling [66], the outcome of single category programmes are lacking evidence:

“Other than for Tai Chi, there was no evidence that single category programmes were effective, for example balance retraining or muscle strengthening exercises alone.” [66].

Likewise there has been performed little research of this kind in the area of exergames as a tool to perform such exercises [35].

In the review of the area Larsen et al. [35] found seven studies of RCT’s of exergames. While the review indicate overall positive effect of exergames (6 out of 7 have positive effect) there is still lack of evidence on the use of exergames as an effective intervention for elderly people as a means against falls. The goal of this project is to investigate and validate the use of one type of exergaming training tool (the IMT) to prevent loss of function and decrease chance of falls among elderly people. The project will compare training with the IMT to usual care in the field with the aim of investigating whether the playing element will result in an improved physical progress compared to usual care.

In 2012 a pilot study of the use of the IMT in municipalities with no control group was conducted. This initial pilot study in Gentofte municipality in Denmark showed that the use of playware technology for training and play can provide statistically significant progress in several of the parameters used to measure the risk of falls among the elderly. The pilot study in Gentofte municipality with 16 participants showed that there is significant improvement in the balance (65%), endurance (6 minute walking test) (26%), strength in the lower body/chair stand (20%) and dynamic balance and agility (Timed Up and Go) (18%) after just ten training times of 12-15 minutes per. time. In addition to the physical benefits, it was highlighted in subsequent interviews that it was fun to work out on the tiles, and 80% wanted to continue with this kind of training [2].

The indications from this pilot study and a MAST [131] investigation of the playware technology have indicated the need for a RCT study to validate both the technology and play as a motivation for exercises among elderly to prevent loss of functionality and falls.

G.7 Objectives

The research hypothesis is that playful training here in the form of the IMT, will make participant perform better on the follow-up tests (6-Minute Walk Test (6MWT), the 8-foot Timed Up & Go Test (TUG), and the Chair-Stand Test (CS) from the Senior Fitness Test [30], than participants not using the IMT. Further it is expected that the participant will perform better on balancing tests (static test on Wii Board and Line Walk test), have a high degree of adherence (participation in +90% of the training), express that IMT is motivating for the training and IMT have a high acceptability.

G.8 Trial design

G.8.1 Design

This study will investigate the use of one form of exergames called IMT how this compared to usual care of elderly people 70+. The trial will consist of two groups, one for training with the IMT and usual care that will receive the care provided to non-patients elderly, which at this moment is no additional treatment other than recommendations.

The study will be single blinded, randomized controlled trial. It will be funded by the patient@home project and Entertainment robotics. Concealed allocation and intention-to-treat analysis will be used. Measurements will be taken at baseline and after intervention. Upon acceptance the protocol will be registered in clinicaltrials.gov.

The trial's results will be reported using domains and categories described in the taxonomy developed by the Prevention of Falls Network Europe, to allow future synthesis of evidence, or study replication [157].

G.9 Study settings

In Denmark, care for the elderly by the municipalities consists of many different services. Care is given in form of nursing homes, day centers and care at the private homes depending on the elderly and their abilities. The care is granted by the municipalities, and is an ongoing negotiation on the amount of money for elderly care and other services provided by the municipalities.

Activities for elderly consist of volunteer activities such as gymnastics (local teams often with public support), day centers where elderly is screened and appointed to, or rehabilitation normally after operations or hospitalization. In a recent study [2] elderly at a day center participated in exercising with playware technology.

In this study the participants will be participating in training at facilities appointed by the participating municipalities. The training will consist of two weekly group training session for the participants (as described in section 11. Intervention).

G.10 Inclusion and exclusion criteria

G.10.1 Inclusion criteria

Community-dwelling men and women aged 70 and above will be included in the project. As the project is a preventive study there is no special requirements to the participants other than the above.

G.10.2 Exclusion criteria

Participants will be excluded if any of the following are identified:

- A previous diagnosis of strong dementia or a cognitive decline that prevents the understanding of simple instructions or guidelines;

- A previous stroke with a severe neurological impairment, such as loss of strength, and perceptual or language limitations;

- A severe visual deficiency;

- Inability to maintain a standing position, even with the use of a walking aid or other device;

- Participating in rehabilitative training.

G.11 Intervention

As recommended by in the TIDieR guidelines [150] the intervention is described using the TIDieR template and displayed in figure G.3. Intervention description as per TIDieR [150].

G.12 Outcome

G.12.1 Primary outcome

The primary outcome measures using pre- and posttests of the TUG, 6MWT and CS. The tests 6MWT, TUG and CS are described in the Senior Fitness Tests Manual [30]. The Senior Fitness Test [30] score fitness standards (performance cut points) that are associated with older adults ability to function independently. More than 2000 older adults have been scores, and the cut points' accuracy and consistency

1. Brief name	Efficacy of Interactive Modular Tiles training versus "usual care" on physical attributes among elder adults 70+. A randomized controlled trial.
2. Why	Falling among elder is a costly problem. Research shows that training can help prevent falls. Pilot studies of the use of Interactive Modular Tiles (IMT) show that the participants can highly increase their physical abilities (Lund and Jessen 2014).
3. What (materials)	The interventions group will train using interactive modular tiles. The tiles include preprogrammed games that create playful training for the participants. The tiles are described in Lund and Jessen (2014). The control group will receive "usual care", which here refers to normal day activities.
4. What (procedures)	The intervention is done in the form of groups of 4-5 participants per set of tiles, with 2-3 set of tiles at a time. As more set can be used it is possible to make groups of more people. The training will consist of 1.5-3 minutes of training (depending on the game) on tiles and the rest while the other 2-3 participants train (4-6 minutes of break). Then the participants will train for 1.5-3 minutes again until each participant have received a total of 13 minutes of training. The control group will not train.
5. Who provided	Research assistant and PhD student with experience in handling the tiles will provide the training of the intervention group.
6. How delivered	Training sessions will be held two times a week and facilitated in groups of 4-5 participants per tiles set. Training will be done in 1 hour sessions, and care will be taken to assure that each participant will get 13 minutes of training per session.
7. Where delivered	Training will be executed at day centers for elderly and/or gymnastics halls of the municipality. The location will have easy access for the participants and room for both chairs (for sitting while on "break") and the tiles.
8. When and how much	The intervention will be done 2 times a week for 12 weeks, each session lasting 1 hour and each participant receiving 13 minutes of training each time (see training plan).
9. Tailoring	All participants will receive the same treatment as the rest of their group (intervention or control). To ensuring that training for the intervention group is both fun and playful new games and/or changes in games can be done during the trial.
10. Modifications	Any changes/modifications will be described and explained in this section after the intervention, including the adding/changing of games.
11. How well (planned)	Training will be delivered independently in each of the training facilities. All trainers will adhere to a single training protocol to ensure standardized delivery of the training across facilities. To ensure standardization of the training the trainers will discuss the training during the trial and the project manager will continuously act as observer and provide feedback to trainers with a view to further standardizing the training. The number of times the participants is present will be recorded at each session, it will also be recorded what games and the time played for each participant.

Figure G.3: TIDieR description of the intervention.

have been validated as clear predictors of physical independence. The test can classify each individual into one of four levels (above average, normal range, below average, or low functioning) and can be used to assess the individual's health risk level.

Three different tests from the Senior Fitness Test [30] are focusing on health risk prevention, such as mobility, agility, balancing, and general fitness, and are well established for testing a variety of health parameters in community-dwelling elderly. These tests include the 6MWT, the 8-foot TUG, and the CS.

Studies have shown that the 6MWT can be used as a fall risk indicator specifically for frail elderly [167]. Furthermore, the 6MWT not only measures aerobic fitness and mobility, but also incorporates components of leg strength, balance, reaction time, and vision.

It has been shown that the TUG reflects a combination of sensory, motor, and strength abilities [168] and can be used to measure of functional mobility [87]. It has also been shown that the TUG can be a tool for discriminating between future fallers and nonfallers [167]. It has been demonstrated that the 8-foot version of TUG have similar qualities for agility and dynamic balancing and that this test is a reliable test for predicting future fallers and nonfallers from among the community-dwelling elderly population [169]. The CS measures lower body strength and endurance and the CS has been shown that the CS is a reliable and valid indicator of lower body strength in generally active, community-dwelling older adults [170].

G.12.2 Secondary outcomes

The following secondary outcomes will also be collected as part of the intervention:

- Line Walk test which is a test to measure balance.

- Static Balance will be measured using Wii Balance Board, which have proven to be a valid measure of balance [174]. This measure will be done using an application developed by Francesco Sgró and colleagues [174].

- Adherence to training

- Motivation for training

- Acceptability of IMT

Adherence to the training will be measured by registering the number of times the participants participate and how much they participate at each session. Semi-structured interviews will be done with the participant after the intervention to investigate motivation and acceptability of the IMT.

G.13 Participant timelines

See figure G.4 for the timeline.

G.14 Sample size

The data from the pilot study (described in [2]) was used to do a power calculation. The results for these showed that for a power of 80 there is a need for 20 persons in each group. As the population of community-dwelling elderly is expected to exhibit a high variance in functional abilities (higher than the population of the pilot study) we have increase the number of participants to 30 in each group. This also allows for dropouts from the study, which we experienced before initializing the pilot study.

G.15 Recruitment

Recruitment is initialized upon approval from the Regional Scientific Committee. The process is done in these steps:

The intervention will be announced through social media, relevant websites and posters presented at elderly center around the Copenhagen area, where the tests will be done. These posters will also be distributed to physiotherapists and other cooperators. Oral presentations will be arranged at elder centers to get a direct contact with more potential participants.

Potential participants will contact the scientific staff (project manager) by email or phone and upon contact study information material will be send to the potential participants. The person will be encouraged to read the information material thoroughly and is informed about the study and the possibility of inviting a private counselor to an information meeting. The potential participant will be given at least two days to read the material before contact is made, to secure

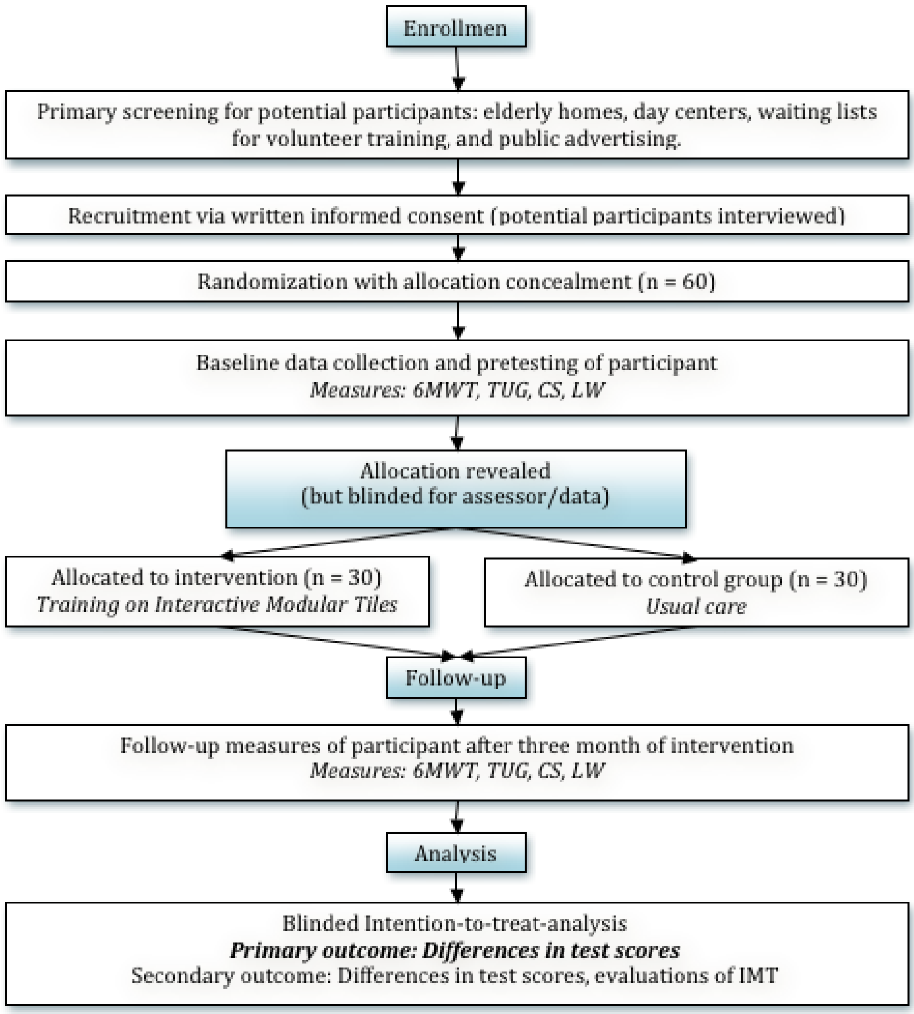

Figure G.4: Participant timeline.

they have enough time to understand the material. Then contact will be taken from the project manager and the participant will be informed orally about the project and will be informed that they are eligible for a private meeting where they can also bring a private counselor. If any inclusion criteria is not meet or any exclusion criteria is identified the person will be informed hereof and the process is discontinued.

If a private information meeting is requested the study information will be presented orally by the project manager in a closed room where only the scientific staff, the potential participant and potentially the private counselor is present. If the potential participant wants additional time to consider whether or not to participate in the study they can return the consent form in a free post envelope (after at least 24 hours) or an agreement about a phone meeting within 48 hours will be made. The potential participant will be informed of the possibility of contacting the project manager by phone, in case of questions.

If the interested persons are eligible for participation and oral and written informed consent is provided, the participant is included in the study and invited to participate in the trial and scheduled for a pre-test. The participant is informed that the later steps can result in exclusion if any exclusion criteria are identified. In case of exclusion the participant will be informed about the reason.

G.16 Allocation

The trial will use “simple randomization” as this is the best randomization for bias prevention and secures unpredictability [136]. A computer will generate random numbers and the participants will be randomized using these numbers, and assigned to control or experimental group with a 1:1 allocation. The randomization will occur as the participants are recruited, after pre-testing. The allocation sequence and assignment will be done by two different third party outside the trial. The enrollment will be by the involved municipalities who have no other role in the project other than recruiting participant and supplying training location.

G.17 Blinding

Due to the nature of the intervention neither patient nor staff can be blinded to the allocation. These will be strong reminded not to disclose the allocation status of the participants at the post-testing. The outcome assessors (pre- and posttest) and data analysis will be blinded from the intervention and randomization.

The project will be assessor and data analysts blinded. It will be stressed to both the participants and others with relations to the project that they may not under any circumstances reveal to the assessor what group they are in. Assessment regarding physical progress for the participant will be conducted by an external company with expertise in doing assessments of physical health. The assessors will be blinded to the treatment allocation. Data analysis will be done by an analyst blinded to the intervention.

G.18 Data collection methods

Outcome measures will be collected as explained earlier. The validity and reliability of these tests are high as described elsewhere [30]. These data will be collected using data baseline and follow-up collection forms as presented in appendix A and B. For the duration of the intervention data about the participation in the training sessions and amount of training in the session will be collected using training data form presented in appendix B. These data will be uploaded and stored at a secure database for data analysis later.

G.18.1 Retention

Getting data from the follow-up tests are vital for the trials validity and statistical power, thus it is of focus to get the participants to participate in the follow-up tests along with the training. The study is focused on the physical abilities of the participants and former pilot studies have shown that the participants have a big interest in knowing their own abilities, and as such it will be stressed that the elderly will get feedback on their abilities and progress in the follow –up test. Participants will also be able to get the general results of the study after the trial.

It is expected that less than 10% (= 6 persons) of the participants will withdraw from the project as the project period is relatively short.

G.19 Data management

Each participant will be given a “trial number” which will correspond to their CPR number on one document. This is done purely to secure that information can be tracked back at a later point, but the document coupling the CPR number and the trial number will be created at recruitment, but for ethical reasons it will be hidden away behind double closed doors (in a cabin in an office at the university of the trial). Any following information will be based on the trial number.

The baseline data of the participants will be registered in a pre-developed form (see appendix G.5. This form will only be used at data analysis, and as such this information will be hidden away along with the CPR numbers.

Pre- and posttests will be done at pre-developed forms (see appendix G.5), where the assessor will supply the data. To secure blinding pre- and posttests will be recorded on separate documents. Participation/adherence data will be collected during the study by the training staff at every session using the training collection form in appendix B. Activity during sessions will be recorded at the adherence form (see appendix G.6).

Data will be entered into a excel sheet with restricted (password protected) access placed on a secure server at the Technical University of Denmark. Information will be check for consistency and backup of the data will be done on a weekly basis.

The Danish Act on Processing of Personal Data will be obeyed.

G.20 Statistical methods

G.20.1 Primary outcome analysis

Data will be collected from pre- and post-tests. Data will be analyzed for statistically significant differences by first checking that there is a Gaussian distribution and the using paired t-test, otherwise using Wilcoxon signed-rank test. The Wilcoxon Signed-Rank Test is selected because the population of community-dwelling elderly is expected to exhibit a high variance in functional abilities. Therefore a normal distribution of the population's test scores cannot be assumed. The Wilcoxon Signed-Rank Test is a statistical hypothesis test suitable under such circumstances.

"Intention to treat" analysis will be done. These two conditions (ie, all participants, as randomized) are widely recommended as the preferred analysis strategy.

G.20.2 Secondary outcome analysis

Data from the LW test will be calculated in the same way as the primary outcomes.

Adherence will be calculated for the average and standard deviation for the participant. This will be compared to a goal of minimum 90% adherence to training.

Motivation will be based on the average scores and standard deviation from the participant interviews (questionnaire on motivation) as will the acceptability.

G.21 Monitoring

As the trial is for a very short duration and the known risks in the intervention are minimal (intervention is physical exercise much in the style already offered to participant), there will be no monitoring of health related issues during the intervention. Data input into the system will be monitored at checked for errors in the input. This will be done partly automatically (is the information valid format), partly on manual checks of the data.

G.22 Harms

Previous pilot studies have revealed no harms from the intervention. The only adverse effect of the trial have been dizziness as some participants have expressed they could feel dizzy during the intervention. Previous trials also revealed that many of these participants felt less dizzy as the intervention progressed.

G.23 Ethical considerations

An important ethical considerations in this project is the activities of the control group. While the optimal solution will be to allow all participants to train, this will greatly increase the cost and length of the trial and not give any results on the use of the IMT as a training tool.

In this study part of the investigation is whether or not the IMT provides a significant improvement of the participants functional abilities. As the participants are being tested before and after, there is a concern that the focus on their abilities will make them focus more on their daily activity level and thus lead to an increased activity and a better score in the follow up ().

As the IMT will be distributed to the municipalities participating in the trial, the municipalities can allow the control group to train on the IMT after the intervention, should the results prove that the training is providing significant results for the intervention group.

G.24 Ethical committee approval

This protocol will be reviewed and approved by the sponsor and the applicable ethical committee with respect to the scientific content and compliance with applicable research and human subjects regulations in Denmark. The protocol will be refined after these reviews in regards to the comments given here.

Any modifications to the protocol which may impact on the conduct of the study, including changes of study objectives, study design, study procedures or significant changes to participant population or sample size will require a formal amendment to the protocol.

G.25 Informed Consent

Representatives from the municipality involved in the study will inform potential participants about the study. Afterwards JDJ will inform the participant about the study and gather informed consent from the participants. JDJ have participated in former pilot trials and have a deep understanding of the project and the demands from the participants, as such he is qualified to give the needed information and allow for questions from the participants about the project before they sign the informed consent.

G.26 Confidentiality

All study-related information will be stored at the sponsoring university at secure sites. All person identifiable information will be securely stored after guidelines presented by the "Datatilsynet". Digital data will be stored at a password protected server space, while all non-digital information will be stored behind double locked doors for the trial period + 2 years. After this all person identifiable data will be deleted and only non-identifiable data will be kept.

After informed consent is retrieved the participants will be enrolled in the project, if they pass the exclusion and inclusion criteria described earlier. All participants will receive a depersonalized code that will follow them for the remainder of the project. The code will be created be a random number sequence, and the translation form for translating the code to the personal information will be keep at a secure location as described earlier.

All information collected data (both during and after the study) will only be accessible by the study investigator, who will grant access to any participants needing access after a formal application.

G.27 Declaration of interests

HHL is a director of the Entertainment Robotics Company, which produced the modular interactive tiles. JDJ declares no competing financial interests exist

G.28 Access to data

JDJ and HHL will have full access to the data after it has been locked in the dataset. The anonyms data will also be send to the statistician for analysis.

G.29 Dissemination

G.29.1 Trial results

Scientific results, both negative, positive and inconclusive, from the trial will be presented to the public through peer-reviewed articles in international journals, national and international scientific conferences, lectures in professional societies, Ph.D. defense and layman articles and presentations.

G.29.2 Reproducible research

The study protocol will be published before the trial is initialized, to secure that the trial can be reproduced. Any updated information in the protocol during the study will be updated and published after the trial.

G.30 Appendix Baseline collection form

Protokol-IMT_v1.1_21052015 - Bilag A
DTU Elektro

DTU

Playware technology for balance training
- A randomized controlled trial.

Baseline-skema	**Deltagernummer:**		**Startdato**	**Slutdato**
Dato	Tests og resultat		Evt. kommentarer	Fremmøde = X Afbud = A Udeblivelse = U
Pre-test	Timed Up and Go:			
	Chair Stand:			
	6 Minute Walking Test:			
	Line Walk:			
	Wii Balance Board file:			
	Højde:			
	Vægt:			
	BMI:			
Post-test	Timed Up and Go:			
	Chair Stand:			
	6 Minute Walking Test:			
	Line Walk:			
	Wii Balance Board file:			
	Højde:			
	Vægt:			
	BMI:			

CVR-nr. DK 30 06 09 46

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Figure G.5: Baseline collection form.

G.31 Appendix Training collection form

Protokol-IMT_v1.1_21052015 - Bilag B
DTU Elektro

Playware technology for balance training
- A randomized controlled trial.

Trænings-skema	Deltagernummer: ____________	Dato for start: ______	Dato for slut: ______
Dato/ Interventions uge	Træningsprogram + tid pr spil	Evt. kom-mentarer	Fremmøde = X Afbud = A Udeblivelse = U
Uge 1a	1 2 3 4 5 6 7		
Uge 1b	1 2 3 4 5 6 7		
Uge 2a	1 2 3 4 5 6 7		

CVR-nr. DK 30 06 09 46

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Figure G.6: Training collection form.

Paper H

MAST analysis of MOTO tiles

This analysis is in danish and builds on [131].

H.1 Titel på løsningen:

Modulære interaktive fliser

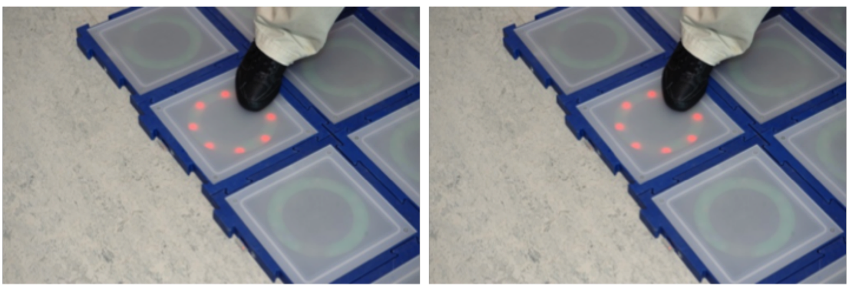

Figure H.1: Modulære interaktive fliser.

H.2 D1: Helbredsproblem og teknologi

Målgruppen: Ældre medborgere med balanceproblemer og stigende risiko for faldulykker. Ældre borgere, der er meget stillesiddende har en stigende risiko for at faldulykker, 1/3 af ældre borgere over 65-80 falder mindst én gang om året, mens det er hver anden 80+ (Sund by Netværk 2010, Pedersen 2012). Indlæggelser i forbindelse med fald udgør ca. 13.000 pr år i 2005, og forventes at stige til næsten 24.000 pr år i 2030. 10-20% af faldene resulterer i alvorlige skader, omkring 5% er knoglebrud og 1% hoftebrud. 20% dør indenfor et år efter faldet [72, 220, 32].

Teknologien: De modulære fliser muliggør træning af legende karakter, hvilket i test har vist at deltagerne glemmer tid og sted og derfor træner længere og mere intensivt. Teknologien består af modulære digitale fliser 30 x 30 cm og en højde på 2,6 cm. Fliser placeres på gulv og kan sættes sammen således, at afstande passer til den pågældende bruger.

Fliserne betjenes dels ved at sætte dem sammen som puslespilsbrikker dels ved anvendelse af RFID-kort (Radio Frequency IDentification). Desuden skal fliserne tages fra hinanden efter brug og placeres i en oplader. Opsætning og adskillelse tager et minut.

H.3 D2: Sikkerhed

Patientsikkerhed: Fliserne er ikke i sig selv et problem for patientsikkerheden. Dog er der risiko for fald i brugen af dem, hvis patienterne har meget dårlig balance. Risikoen kan nedsættes ved at bruge fx gåbarrer eller andet udstyr. Træning på fliserne kan medføre svimmelhed. Dog viser pilotforsøg at svimmelheden vil aftage gradvist efterhånden som patienterne træner.

Personalesikkerhed: Fliserne vejer ikke meget hver for sig, men de kræver at man bevæger sig rundt på gulvet, når de skal samles. Derfor skal medarbejderne være opmærksom under opsætning og nedtagning af fliserne.

Fliserne arbejder med svagstrøm med indbygget genopladeligt batteri ved en spænding på 3,7 volt. Opladning sker i oplader. Fliser og oplader er CE-mærket.

Driftsikkerhed: Fliserne er generelt stabile. Evt. problemer kan dog nemt ordnes, da fliserne er modulære. Skulle en flise blive defekt, kan denne udskiftes/frakobles, og der kan fortsættes med de resterende.

H.4 D3: Klinisk effekt

Fliserne har været anvendt i forsøg på hospitaler og kommuner (se nedenstående skema, samt [200, 233]).

Desuden er fliserne anvendt i to effektstudier, som har vist meget positive effekter (se tabel 1). Første forsøg var i Gentofte kommune med 16 ældre personer (63-95 år, gennemsnit 83,2 år). I dette forsøg blev de ældre teste med tests (Chair Stand (CS), Timed Up and Go (TUG) og 6 Minute Walk Test (MWT)) fra Senior Fitness Test, som er valideret med mere end 2000 ældre [30]. Desuden blev de teste med Line Walk (LW) en test for balance. Resultaterne af testen ses i figur H.2.

Test	Pre-test	Post-test	Gennemsnitlig forbedring	Signifikans	Niveauer af forbedringer
CS	9,9	12,3	24 %	P<0,001	7
TUG	11,7 s	9,3 s	21 %	P<0,001	6
6MWT	269,8 m	347,9 m	29 %	P<0,001	5
LW	3,8	6,3	66 %	P<0,001	NA

Figure H.2: Forbedringer på pre- og posttest, Senior Fitness Test.

Forbedringer i niveauer henviser til personer, der ved post-testen var rykket fra et risikoniveau til et bedre niveau (i forhold til Rikli og Jones' [30] reference points).

Andet forsøg var i Lyngby-Taarbæk kommune med 12 ældre (66-88 år, gennemsnit 79 år). I dette forsøg brugte kommunen Dynamic Gait Index (DGI) til at teste de ældre. DGI bruges til at teste dynamisk balance på ældre, som er central for at undgå fald blandt ældre. Resultaterne ses i tabel H.3.

	Pre-test	Post-test	Forbedring	Signifikans
Kontrolgruppe	18,3	16,6	-9,3 %	NS
Interventionsgruppe	19,0	21,3	12,3 %	P<0,05

Figure H.3: Forbedringer på pre- og posttest, DGI.

Samlet set viser forsøgene at deltagerne får en signifikant fremgang, som har stor effekt på deres faldrisiko.

H.5 D4: Patientens perspektiver

Interview med deltagerne i forsøget i Gentofte har vist, at der er en stor grad af tilfredshed med brugen af teknologien. 84% af deltagerne mener, at teknologien har levet op til deres forventninger, og 61% fremhæver det legende element som det vigtigste, mens ca. en tredjedel mener at fysiske forbedringer har været det vigtigste.

Generelt har patienterne givet udtryk for, at det er nemt at anvende fliserne, samt at den øgede fysiske styrke har givet mulighed for at gøre flere ting selv.

H.6 D5: Økonomiske aspekter

Sund By Netværket skriver i sin rapport med anbefalinger vedrørende ældres faldulykker [234]:

"Flere faldulykker jo ældre befolkningen bliver"

I de kommende år vil den ældre del af befolkningen udgøre en markant større andel af den samlede befolkning, end den gør i dag. Da konsekvenserne af et fald bliver alvorligere med stigende alder, må det forventes, at de samfundsøkonomiske konsekvenser af ældres faldulykker vil vokse betydeligt, med mindre der gennemføres effektive forebyggende initiativer.

En fremskrivning af antallet af indlæggelser baseret på udviklingen i befolkningens sammensætning viser, at antallet af indlæggelser, som følge af fald, vil være forøget fra ca. 13.000 indlæggelser i 2005 til næsten 24.000 indlæggelser i 2030.

Samfundsøkonomisk perspektiv Ifølge en engelsk undersøgelse koster fald blandt ældre et beløb svarende til ca. 2% af sundhedsudgifterne. Ca. 60% af omkostningerne er i sygehussektoren, og ca. 40% går til pleje mv. Overføres tallene til danske forhold, koster fald blandt ældre ca. 2 mia. kroner, hvoraf ca. 800 mio. kr. er omkostninger i kommunerne.

Opgjort pr. faldrelateret hoftebrud blandt ældre, svarer dette til knap 200.000 kr. for samfundet, hvoraf ca. 80.000 er kommunale omkostninger. Disse engelske tal stemmer overens med resultaterne fra en dansk undersøgelse fra 1994, der fandt, at de samfundsmæssige omkostninger relateret til et hoftebrud var 147.000, svarende til ca. 202.000 kr. i 2009-kroner. Der foreligger ikke tilstrækkelige danske opgørelser over de samfundsøkonomiske gevinster ved at lave en faldforebyggende indsats.

Målrettet faldforebyggelse nytter Ældre, som har oplevet at falde, bliver ofte bange for at falde igen. Frygten begrænser hverdagslivet og evnen til at færdes, hvilket kan føre til social isolation. En reduktion af faldulykker vil have positiv betydning for ældres livskvalitet og spare ressourcer på sundheds- og socialområdet.

Det er veldokumenteret, at faldforebyggelse har en positiv effekt. Svækket muskelstyrke og ringe balance er ofte udløsende faktorer for et fald, hvorfor opbygning af muskelstyrke gennem individuelt tilpasset træning, og reduktion af risikofaktorer med udgangspunkt i boligændringer, er centrale i faldforebyggelse hos ældre. D-vitamin i kombination med calcium har endvidere vist effekt i forhold til at mindske risikoen for og konsekvenserne af fald.

Faldforebyggelse er dog mest effektiv, når forebyggelsen rettes mod de ældre, der har forøget risiko for at falde. Derfor er det vigtigt at have kendskab til de mangeartede risikofaktorer for at kunne tilpasse interventioner til den enkelte.

En evaluering af Sund By Netværkets erfaringer med forebyggelse af ældres faldulykker har fundet, at faldforebyggelse virker, idet forekomsten af faldulykker i netværkets område er reduceret i perioden 1998-2005, og er lavere end i resten af landet."

Sundhedsøkonomisk beregning Blandt ældre 80+ år falder 50% mindst en gang om året (og blandt ældre 65+ år falder 33%). En tredjedel af fald kræver lægehjælp [235]. Et sådant skadefuldt fald medfører ifølge Rizzo et al. [236] en omkostning på cirka 28.000$ omregnet til 2014-priser eller cirka 150.000 kr, medens fald der ikke kræver lægehjælp beregnes til at give ekstra Medicare udgifter på cirka 15.000 kr i 2014-priser [235].

Det er vist, at træningsprogrammer kraftigt reducerer antal fald og specielt risikoen for de dyre fald-relaterede frakturer med 66% [66], og at specifikke træningsprogrammer kan reducere faldrisikoen med 55% [237]. Det antages, at der med 2 sæt fliser trænes cirka 250 ældre 80+ år på et år. Der vil normalt blandt disse være 125 fald. 69 af disse fald kan undgås med specifikt træningsprogram. Af disse 69 fald ville 23 fald kræve lægehjælp og 46 fald ikke kræve lægehjælp. Den samlede besparelse vil være 23*150.000 kr + 46 * 15.000 kr = 4.140.000 kr. Udgiften til 2 sæt fliser i leasing (4.990kr / måned) vil være 2*12*4.990 kr =

119.790 kr. Den samlede årlige besparelse ville dermed være cirka 4 millioner kr.

Derudover vil der være besparelser fra færre forflytninger til plejehjem, idet Kennedy og Coppard har vist at fald er betydende faktor i henimod halvdelen af alle forflytninger til plejehjem [238]. Desuden vil der værre langt færre udgifter til pleje som resultat af færre fald. Således vil besparelsen pr 2 sæt fliser langt overstige 4 millioner kr årligt.

Der vil desuden være personaleudgifter og udgifter til optræningskurser (inkl. Screening af ældre, Afsættelse af træningstid samt lokation, Tovholder, Opstart af træning, Løbende test/sikring af fremskridt). Denne udgift estimeres til cirka 50.000-75.000 kr. pr 2 sæt fliser.

Ved flere ældre 65+år, færre ældre i træning, vil besparelsen blive mindre. Hvis halvdelen af deltagerne er 65-79 år og halvdelen 80+ år, vil der i gruppen af 250 deltagere være 104 fald. Den årlige besparelse vil efter udgift til fliserne være 3.3 millioner kr. samt aflede besparelser (såsom færre forflytninger til plejehjem).

H.7 D6: Organisatoriske aspekte

Brugen af fliserne kræver ikke større uddannelse eller organisatoriske ændringer. Dog har erfaringer fra tidligere vist, at en tovholder ofte vil forbedre udbyttet at brugen betragteligt. Ligeledes kræves der en accept af teknologien i organisationen.

Brugen af fliserne bør indføres med tanke for de strukturelle ændringer, der vil være brug for at gennemføre, herunder:

- Tid og plads til brugen af fliserne. Kan blot være i et almindelig lokale med god gulv plads
- Tid til tovholder
- Evt. kulturelle ændringer i holdningen til træning og leg blandt ældre

Interview med fysioterapeuter fra tidligere forsøg har desuden vist, at fliserne generelt er nemme at anvende for både patienter og personale. Desuden er stabilitet og driftsikkerhed et stort fokus punkt for disse brugergrupper.

Med indførelsen af teknologien til genoptræning/træning af ældre mennesker, vil en del arbejde kunne glide fra hospitaler til hjem og fra kommunale gentræningscentre til private hjem, idet teknologien gør det nemmere og mere motiverende at varetage selvstændig træning i private personers hjem. Genoptræning kan gøre brug af fliserne, som gør patienterne mere selvhjulpne, da de skal blot igangsættes. Personalet skal således sætte fliserne frem og instruere i deres brug de første gange, hvorefter patienten selv vil kunne varetage træningen

En større ændring gælder dog i forebyggelsesarbejdet. For at teknologien kan bruges i praksis, skal der organisatoriske ændringer i forhold til, hvordan teknologien fordeles og bruges i dagligdagen.

H.8 D7: Etiske, juridiske og sociokulturelle aspekter

Der vurderes ikke at være etiske eller juridiske problemer ved indførelsen af teknologien. Fliserne er CE-mærket og lever ifølge producenten op til gældende lovkrav.

Fliserne indfører en ny, sjov måde at træne på, som i pilotstudier har vist sig effektive. Der er vurderes derfor heller ikke at være sociokulturelle problematikker i forbindelse med teknologien

H.9 Kontaktoplysninger på den person der har udfyldt skemaet

Table H.1: Kontaktoplysninger

Navn	Jari Due Jessen
Stilling	Ph.d. studerende
Organisation	Center for Playware, DTU
E-mail	jdje@elektro.dtu.dk
Telefon	31182137
Arbejdspakke (WP)	1.1
Version (sæt kryds)	G2: __ G3: __ G4: __
Dato	5/9-14

Bibliography

[1] H. H. Lund and J. D. Jessen. “Effect of Playful Balancing Training-A Pilot Randomized Controlled Trial”. *2013 ISAROB* (2013).

[2] H. H. Lund and J. D. Jessen. “Effects of short-term training of community-dwelling elderly with modular interactive tiles”. *GAMES FOR HEALTH: Research, Development, and Clinical Applications* 3.5 (2014), pp. 277–283.

[3] J. D. Jessen, H. H. Lund, and C. Jessen. “Physical computer games for motivating physical play among elderly”. *Gerontechnology* 13.2 (2014), p. 220.

[4] J. D. Jessen and C. Jessen. “Games as Actors”. *International Journal on Advances in Intelligent Systems* (2014).

[5] J. D. Jessen and H. H. Lund. “Playful home training for falls prevention”. *Advanced Intelligent Mechatronics (AIM), 2015 IEEE International Conference on*. IEEE. 2015, pp. 311–317.

[6] C. Jessen, H. Lund, and T. Klitbo. “Playware? intelligent technology for children? s play. Technical Report TR-2005-1” (2005).

[7] A. A. Hedley, C. L. Ogden, C. L. Johnson, M. D. Carroll, L. R. Curtin, and K. M. Flegal. “Prevalence of overweight and obesity among US children, adolescents, and adults, 1999-2002”. *Jama* 291.23 (2004), pp. 2847–2850.

[8] M. Lindstrom. *Brandchild: remarkable insights into the minds of today’s global kids and their relationship with brands*. Kogan Page Publishers, 2004.

[9] S. Kline. *Out of the Garden: Toys, TV, and Children's Culture in the Age of Marketing*. Verso, 1995.

[10] N. Postman. "The disappearance of childhood". *Childhood Education* 61.4 (1985), pp. 286–293.

[11] C. Jessen and H. Lund. *Playware - Intelligent Technology for Children's Play*. 2008.

[12] B. Sutton-Smith. *Toys as Culture.* ERIC, 1986.

[13] F. Mouritsen. *Child culture-Play culture*. Department of Contemporary Cultural Studies, Odense University, 1998.

[14] C. Jessen and C. Nielsen. "The Changing Face of Children's Play Culture: Children's Play, Learning and Communication in a Technology Driven World". *Denmark: LEGO Learning Institute* (2003).

[15] H. H. Lund. "Building bodies and brains". *Adaptive Behavior* (2014), p. 1059712314544177.

[16] H. H. Lund, B. Webb, and J. Hallam. "A robot attracted to the cricket species gryllus bimaculatus". *4th European Conference on Artificial Life*. 1997, pp. 246–255.

[17] E. Nieuwdorp. "The pervasive discourse: an analysis". *Computers in Entertainment (CIE)* 5.2 (2007), p. 13.

[18] H. H. Lund. "Modular robotics for playful physiotherapy". *Rehabilitation Robotics, 2009. ICORR 2009. IEEE International Conference on*. IEEE. 2009, pp. 571–575.

[19] H. H. Lund and P. Marti. "Designing modular robotic playware". *International Symposium on Robot and Human Interactive Communication*. 2009, pp. 115–121.

[20] J. Nielsen, N. K. Brendsen, and C. Jessen. "RoboMusicKids–music education with robotic building blocks". *Digital Games and Intelligent Toys Based Education, 2008 Second IEEE International Conference on*. IEEE. 2008, pp. 149–156.

[21] K. Falkenberg, N. K. Bærendsen, J. Nielsen, C. Jessen, and H. H. Lund. "RoboMusic with modular playware". *Artificial Life and Robotics* 15.4 (2010), pp. 369–375.

[22] M. Pacheco, R. Fogh, H. H. Lund, and D. J. Christensen. "Fable II: Design of a modular robot for creative learning". *Robotics and Automation (ICRA), 2015 IEEE International Conference on*. IEEE. 2015, pp. 6134–6139.

[23] H. H. Lund and P. Marti. "Designing manipulative technologies for children with different abilities". *Artificial Life and Robotics* 9.4 (2005), pp. 175–187.

[24] H. H. Lund. "Modular Playware Technology: A Brief Historical Review". *2012 Seventeenth International Symposium on Artificial Life and Robotics*. 2012.

[25] H. H. Lund and M. Ottesen. "RoboMusic: a behavior-based approach". *Artificial Life and Robotics* 12.1-2 (2008), pp. 18–23.

[26] H. H. Lund. "Lessons Learned in Designing User-configurable Modular Robotics". In: *Robot Intelligence Technology and Applications 2*. Springer, 2014, pp. 279–286.

[27] P. Marti, H. H. Lund, M. Bacigalupo, L. Giusti, and C. Mennecozzi. "A multi-sensory environment for the treatment of dementia affected subjects". *Gerontechnology* 6.1 (2007), pp. 33–41.

[28] P. Marti and L. Giusti. "Coupling the digital and the physical in therapeutic environments". *Human-Computer Interaction. Interaction Platforms and Techniques* (2007), pp. 1173–1182.

[29] H. H. Lund, T. Klitbo, and C. Jessen. "Playware technology for physically activating play". *Artificial life and Robotics* 9.4 (2005), pp. 165–174.

[30] R. E. Rikli and C. J. Jones. *Senior fitness test manual*. Human Kinetics, 2013.

[31] C. J. Jones and R. E. Rikli. "Measuring functional". *The Journal on active aging* 1 (2002), pp. 24–30.

[32] G. K. Forebyggelse og Sundhedsfremme. *Evaluering af projektet: De legende mennesker*. 2013. URL: `http://goo.gl/Y9Y2xT` (visited on 01/06/2016).

[33] A. Shumway-Cook and M. H. Woollacott. *Motor control: theory and practical applications*. Lippincott Williams & Wilkins, 1995.

[34] A. Shumway-Cook, M. Baldwin, N. L. Polissar, and W. Gruber. "Predicting the probability for falls in community-dwelling older adults". *Physical therapy* 77.8 (1997), pp. 812–819.

[35] L. H. Larsen, L. Schou, H. H. Lund, and H. Langberg. "The physical effect of exergames in healthy elderly—a systematic review". *GAMES FOR HEALTH: Research, Development, and Clinical Applications* 2.4 (2013), pp. 205–212.

[36] P. M. Kato. "Evaluating efficacy and validating games for health". *GAMES FOR HEALTH: Research, Development, and Clinical Applications* 1.1 (2012), pp. 74–76.

[37] B. Ferguson. "The emergence of games for health". *GAMES FOR HEALTH: Research, Development, and Clinical Applications* 1.1 (2012), pp. 1–2.

[38] P. M. Kato. "Video games in health care: Closing the gap." *Review of General Psychology* 14.2 (2010), p. 113.

[39] H. Kharrazi, A. S. Lu, F. Gharghabi, and W. Coleman. "A scoping review of health game research: past, present, and future". *GAMES FOR HEALTH: Research, Development, and Clinical Applications* 1.2 (2012), pp. 153–164.

[40] D. A. Lieberman. "Management of chronic pediatric diseases with interactive health games: Theory and research findings". *The Journal of ambulatory care management* 24.1 (2001), pp. 26–38.

[41] A. Au. "Games for Health: Past, Present, and Future?" *GAMES FOR HEALTH: Research, Development, and Clinical Applications* 1.6 (2012), pp. 449–451.

[42] E. Rahmani and S. A. Boren. "Videogames and health improvement: a literature review of randomized controlled trials". *GAMES FOR HEALTH: Research, Development, and Clinical Applications* 1.5 (2012), pp. 331–341.

[43] D. J. Kolko and J. L. Rickard-Figueroa. "Effects of video games on the adverse corollaries of chemotherapy in pediatric oncology patients: a single-case analysis." *Journal of consulting and clinical psychology* 53.2 (1985), p. 223.

[44] W. H. Redd, P. B. Jacobsen, M. Die-Trill, H. Dermatis, M. McEvoy, and J. C. Holland. “Cognitive/attentional distraction in the control of conditioned nausea in pediatric cancer patients receiving chemotherapy.” *Journal of consulting and clinical psychology* 55.3 (1987), p. 391.

[45] J. Vasterling, R. A. Jenkins, D. M. Tope, and T. G. Burish. “Cognitive distraction and relaxation training for the control of side effects due to cancer chemotherapy”. *Journal of behavioral medicine* 16.1 (1993), pp. 65–80.

[46] S. J. Brown, D. A. Lieberman, B. Gemeny, Y. C. Fan, D. Wilson, and D. Pasta. “Educational video game for juvenile diabetes: results of a controlled trial”. *Medical Informatics* 22.1 (1997), pp. 77–89.

[47] D. H. Rubin, J. M. Leventhal, R. T. Sadock, E. Letovsky, P. Schottland, I. Clemente, and P. McCarthy. “Educational intervention by computer in childhood asthma: a randomized clinical trial testing the use of a new teaching intervention in childhood asthma”. *Pediatrics* 77.1 (1986), pp. 1–10.

[48] L. Bartholomew, R. Gold, G. Parcel, D. Czyzewski, M. Sockrider, M. Fernandez, R. Shegog, and P. Swank. “Watch, Discover, Think, and Act: evaluation of computer-assisted instruction to improve asthma self-management in inner-city children”. *Patient education and counseling* 39.2 (2000), pp. 269–280.

[49] P. H. McKENNA, C. A. HERNDON, S. CONNERY, and F. A. FERRER. “Pelvic floor muscle retraining for pediatric voiding dysfunction using interactive computer games”. *The Journal of urology* 162.3 (1999), pp. 1056–1062.

[50] C. A. Herndon, M. Decambre, and P. H. Mckenna. “Interactive computer games for treatment of pelvic floor dysfunction”. *The Journal of urology* 166.5 (2001), pp. 1893–1898.

[51] A. Leahy, C. Clayman, I. Mason, G. Lloyd, and O. Epstein. “Computerised biofeedback games: a new method for teaching stress management and its use in irritable bowel syndrome.” *Journal of the Royal College of Physicians of London* 32.6 (1997), pp. 552–556.

[52] F. Alemi, F. Cherry, and G. Meffert. “Rehearsing decisions may help teenagers: an evaluation of a simulation game”. *Computers in biology and medicine* 19.4 (1989), pp. 283–290.

[53] D. M. Paperny and J. R. Starn. “Adolescent pregnancy prevention by health education computer games: computer-assisted instruction of knowledge and attitudes”. *Pediatrics* 83.5 (1989), pp. 742–752.

[54] J. M. Cahill. “Health works: Interactive AIDS education videogames”. *Computers in Human Services* 11.1-2 (1995), pp. 159–176.

[55] D. A. Lieberman. “Interactive video games for health promotion: Effects on knowledge, self-efficacy, social support, and health”. *Health promotion and interactive technology: Theoretical applications and future directions* (1997), pp. 103–120.

[56] M. S. Tingen, L. F. Gramling, G. Bennett, E. M. Gibson, and M. M. Renew. “A pilot study of preadolescents using focus groups to evaluate appeal of a video-based smoking prevention strategy”. *Journal of Addictions Nursing* 9.3 (1997), pp. 118–124.

[57] J. STRANG. “Is an arcade-style computer game an effective medium for providing drug education to schoolchildren?” *Education for Health* 13.3 (2000), pp. 404–406.

[58] D. Passig and S. Eden. “Enhancing the induction skill of deaf and hard-of-hearing children with virtual reality technology”. *Journal of Deaf Studies and Deaf Education* 5.3 (2000), pp. 277–285.

[59] D. Passig and S. Eden. “Improving flexible thinking in deaf and hard of hearing children with virtual reality technology”. *American Annals of the Deaf* 145.3 (2000), pp. 286–291.

[60] D. Passig and S. Eden. “Virtual reality as a tool for improving spatial rotation among deaf and hard-of-hearing children”. *CyberPsychology & Behavior* 4.6 (2001), pp. 681–686.

[61] D. Passig and S. Eden. “Cognitive intervention through virtual environments among deaf and hard-of-hearing children”. *European journal of special needs education* 18.2 (2003), pp. 173–182.

[62] J. Szer. “Video games as physiotherapy.” *The Medical journal of Australia* 1.9 (1983), pp. 401–402.

[63] J. M. Sietsema, D. L. Nelson, R. M. Mulder, D. Mervau-Scheidel, and B. E. White. “The use of a game to promote arm reach in persons with traumatic brain injury”. *American Journal of Occupational Therapy* 47.1 (1993), pp. 19–24.

[64] A. Krichevets, E. Sirotkina, I. Yevsevicheva, and L. Zeldin. “Computer games as a means of movement rehabilitation”. *Disability and rehabilitation* 17.2 (1995), pp. 100–105.

[65] W. H. Organization et al. *WHO definition of Health*. 1946. URL: `http://www.who.int/about/definition/en/print.html` (visited on 31/05/2016).

[66] L. D. Gillespie, M. C. Robertson, W. J. Gillespie, C. Sherrington, S. Gates, L. M. Clemson, and S. E. Lamb. “Interventions for preventing falls in older people living in the community”. *Cochrane Database Syst Rev* 9.11 (2012).

[67] D. F. Goldspink. “Ageing and activity: their effects on the functional reserve capacities of the heart and vascular smooth and skeletal muscles”. *Ergonomics* 48.11-14 (2005), pp. 1334–1351.

[68] J. E. Dunn, M. A. Rudberg, S. E. Furner, and C. K. Cassel. “Mortality, disability, and falls in older persons: the role of underlying disease and disability.” *American Journal of Public Health* 82.3 (1992), pp. 395–400.

[69] J. L. O’Loughlin, Y. Robitaille, J.-F. Boivin, and S. Suissa. “Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly”. *American journal of epidemiology* 137.3 (1993), pp. 342–354.

[70] C. Brot, T. V. Skjøth, K. Nielsen, H. Backe, and S. H. Livet. *Faldpatienter i den kliniske hverdag: rådgivning fra Sundhedsstyrelsen*. Sundhedsstyrelsen, 2006.

[71] T. Masud and R. O. Morris. “Epidemiology, of falls”. *Age and ageing* 30 (2001), pp. 3–7.

[72] L. Rytter, P. Sørensen, L. Foged, J. Ærthøj, J. Søndergaard, D. Glintborg, B. Degn-Petersen, and E. Damsgaard. *Den ældre patient*. Dansk Selskab for Almen Medicin, 2012.

[73] K. A. Schutzer and B. S. Graves. "Barriers and motivations to exercise in older adults". *Preventive medicine* 39.5 (2004), pp. 1056–1061.

[74] H. Manaf. "Barriers to participation in physical activity and exercise among middle-aged and elderly individuals". *Singapore Med J* 54.10 (2013), pp. 581–586.

[75] B. J. Kooiman and D. P. Sheehan. "Interacting with the past, present, and future of exergames: At the beginning of a new life cycle of video games?" *Loisir et Société/Society and Leisure* 38.1 (2015), pp. 55–73.

[76] M. D. Finco and R. W. Maass. "The history of exergames: promotion of exercise and active living through body interaction". *Serious Games and Applications for Health (SeGAH), 2014 IEEE 3rd International Conference on*. IEEE. 2014, pp. 1–6.

[77] J. van't Riet, R. Crutzen, and A. S. Lu. "How effective are active videogames among the young and the old? Adding meta-analyses to two recent systematic reviews". *GAMES FOR HEALTH: Research, Development, and Clinical Applications* 3.5 (2014), pp. 311–318.

[78] D. M. Harris, T. Rantalainen, M. Muthalib, L. Johnson, and W.-P. Teo. "Exergaming as a Viable Therapeutic Tool to Improve Static and Dynamic Balance among Older Adults and People with Idiopathic Parkinson's Disease: A Systematic Review and Meta-Analysis". *Frontiers in aging neuroscience* 7 (2015).

[79] Y. Laufer, G. Dar, and E. Kodesh. "Does a Wii-based exercise program enhance balance control of independently functioning older adults? A systematic review." *Clinical interventions in aging* 9 (2013), pp. 1803–1813.

[80] L. M. Taylor, N. Kerse, T. Frakking, and R. Maddison. "Active Video Games for Improving Physical Performance Measures in Older People: A Meta-analysis." *Journal of geriatric physical therapy (2001)* (2016).

[81] J. R. Franco, K. Jacobs, C. Inzerillo, and J. Kluzik. “The effect of the Nintendo Wii Fit and exercise in improving balance and quality of life in community dwelling elders”. *Technology and Health Care* 20.2 (2012), pp. 95–115.

[82] G. Pichierri, A. Coppe, S. Lorenzetti, K. Murer, and E. D. de Bruin. “The effect of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: a randomized controlled pilot study”. *Clin Interv Aging* 7 (2012), pp. 175–184.

[83] A. A. Rendon, E. B. Lohman, D. Thorpe, E. G. Johnson, E. Medina, and B. Bradley. “The effect of virtual reality gaming on dynamic balance in older adults”. *Age and ageing* 41.4 (2012), pp. 549–552.

[84] K. Berg, S. Wood-Dauphine, J. Williams, and D. Gayton. “Measuring balance in the elderly: preliminary development of an instrument”. *Physiotherapy Canada* 41.6 (1989), pp. 304–311.

[85] K. O. Berg, S. L. Wood-Dauphinee, J. I. Williams, and B. Maki. “Measuring balance in the elderly: validation of an instrument.” *Canadian journal of public health= Revue canadienne de sante publique* 83 (1991), S7–11.

[86] M. E. Tinetti. “Performance-oriented assessment of mobility problems in elderly patients”. *Journal of the American Geriatrics Society* 34.2 (1986), pp. 119–126.

[87] D. Podsiadlo and S. Richardson. “The timed “Up & Go”: a test of basic functional mobility for frail elderly persons”. *Journal of the American geriatrics Society* 39.2 (1991), pp. 142–148.

[88] C. Anderson-Hanley, P. J. Arciero, A. M. Brickman, J. P. Nimon, N. Okuma, S. C. Westen, M. E. Merz, B. D. Pence, J. A. Woods, A. F. Kramer, et al. “Exergaming and older adult cognition: a cluster randomized clinical trial”. *American journal of preventive medicine* 42.2 (2012), pp. 109–119.

[89] H. Bateni. “Changes in balance in older adults based on use of physical therapy vs the Wii Fit gaming system: a preliminary study”. *Physiotherapy* 98.3 (2012), pp. 211–216.

[90] D. K. A. Singh, B. Rajaratnam, V. Palaniswamy, V. Raman, P. Bong, and H. Pearson. “Effects of balance-focused interactive games compared to therapeutic balance classes for older women”. *Climacteric* 16.1 (2012), pp. 141–146.

[91] J. Kim, J. Son, N. Ko, and B. Yoon. “Unsupervised virtual reality-based exercise program improves hip muscle strength and balance control in older adults: a pilot study”. *Archives of physical medicine and rehabilitation* 94.5 (2013), pp. 937–943.

[92] Y. J. Gschwind, S. Eichberg, A. Ejupi, H. de Rosario, M. Kroll, H. R. Marston, M. Drobics, J. Annegarn, R. Wieching, S. R. Lord, et al. “ICT-based system to predict and prevent falls (iStoppFalls): results from an international multicenter randomized controlled trial”. *European Review of Aging and Physical Activity* 12.1 (2015), pp. 1–11.

[93] K. Salen and E. Zimmerman. *Rules of play: Game design fundamentals*. MIT press, 2004.

[94] K. Salen and E. Zimmerman. *The game design reader: A rules of play anthology*. MIT press, 2006.

[95] B. Sutton-Smith. *The ambiguity of play*. Harvard University Press, 2009.

[96] J. Huizinga. *Homo Ludens: A Study of the Play-element in Cult*. Beacon Press, 1955.

[97] C. Jessen and H. Karoff. “Playware and new play culture”. *Proceedings for BIN Conference*. 2008.

[98] M. Consalvo. “There is no magic circle”. *Games and culture* (2009).

[99] G. Calleja. “Erasing the magic circle”. In: *The philosophy of computer games*. Springer, 2012, pp. 77–91.

[100] J. Stenros. “In defence of a magic circle: The social and mental boundaries of play”. *Proceedings of*. 2012.

[101] G. Bateson. “A theory of play and fantasy.” *Psychiatric research reports* (1955).

[102] R. Caillois and M. Barash. *Man, play, and games*. University of Illinois Press, 1961.

[103] B. Neitzel. “Narrativity in computer games”. *Handbook of computer game studies* (2005), pp. 227–245.

[104] J. H. Kerr and M. J. Apter. *Adult Play - A Reversal Theory Approach*. Swets & Zeitlinger, 1991.

[105] K. D. Lafreniere. “Reversal theory: An introduction”. *Patient education and counseling* 22.2 (1993), pp. 63–71.

[106] M. Apter. “Reversal theory: what is it?” *PSYCHOLOGIST-LEICESTER-* 10 (1997), pp. 217–220.

[107] M. J. Apter. *Motivational styles in everyday life: A guide to reversal theory.* American Psychological Association, 2001.

[108] H. S. Karoff and C. Jessen. *Tekster om leg*. Akademisk Forlag, 2014.

[109] M. Csikszentmihaiyi. *Flow: The Psychology of Optimal Experience/Csikszentmihaiyi M*. 1990.

[110] C. Jessen and H. H. Lund. *En definition af leg*. 2008. URL: `http://goo.gl/ZAyKV4` (visited on 01/06/2016).

[111] B. Latour. “Reassembling the social-an introduction to actor-network-theory”. *Reassembling the Social-An Introduction to Actor-Network-Theory, by Bruno Latour, pp. 316. Foreword by Bruno Latour. Oxford University Press, Sep 2005. ISBN-10: 0199256047. ISBN-13: 9780199256044* 1 (2005).

[112] B. Latour. “Where are the missing masses? The sociology of a few mundane artifacts” (1992).

[113] B. Latour. “A door must be either open or shut: A little philosophy of techniques”. *Technology and the Politics of Knowledge* (1995), pp. 272–281.

[114] B. Latour. “The trouble with actor-network theory” (1997).

[115] M. Callon and B. Latour. “Unscrewing the big Leviathan: how actors macro-structure reality and how sociologists help them to do so”. *Advances in social theory and methodology: Toward an integration of micro-and macro-sociologies* (1981), pp. 277–303.

[116] M. Callon. “Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay”. *The Sociological Review* 32.S1 (1984), pp. 196–233.

[117] M. Ackrich. “The de-scription of technical objects”. *W Bijker and J Law (eds) Shaping Technology/Building Society* (1992), pp. 205–224.

[118] C. Jessen and H. Lund. “On play forces, play dynamics and playware”. *Unpublished manuscript* (2009).

[119] B. Sutton-Smith. *Play and learning*. Vol. 3. Halsted Press, 1979.

[120] B. K. Walther. “Playing and gaming”. *Game Studies* 3.1 (2003), pp. 1–20.

[121] H. G. Gadamer. “Die Aktualität des Schönen Kunst Als Spiel, Symbol Und Fest” (1977).

[122] F. Schiller. “Über die tragische Kunst; Vom Erhabenen; Über das Pathetische”. *Friedrich Schiller, Werke und Briefe in* 12 (), pp. 251–275.

[123] D. G. Singer, R. M. Golinkoff, and K. Hirsh-Pasek. *Play= Learning: How play motivates and enhances children’s cognitive and social-emotional growth*. Oxford University Press, 2006.

[124] U. Eco. “Homo ludens» oggi”. *foreword to the* (1973).

[125] C. Jessen. “Læringsspil og leg”. In: *Digitale medier og didaktisk design*. Danmarks Pædagogiske Universitets Forlag, 2008.

[126] P. Bourdieu. “Af praktiske grunde”. *København: Hans Reitzels forlag* (1997).

[127] ALGA. *Quackle! Manual*. 2006. URL: `http://www.algaspel.se/~/media/Alga/Files/Rules/flersprakiga/38018871_Quackle.ashx` (visited on 02/06/2016).

[128] statita. *Most played PC games on gaming platform Raptr in November 2015, by share of playing time*. 2015. URL: `http://www.statista.com/statistics/251222/most-played-pc-games/` (visited on 02/06/2016).

[129] E. Castronova. *Synthetic worlds: The business and culture of online games*. University of Chicago press, 2008.

[130] B. Costello and E. Edmonds. "A study in play, pleasure and interaction design". *Proceedings of the 2007 conference on Designing pleasurable products and interfaces*. ACM. 2007, pp. 76–91.

[131] K. Kidholm, A. G. Ekeland, L. K. Jensen, J. Rasmussen, C. D. Pedersen, A. Bowes, S. A. Flottorp, and M. Bech. "A model for assessment of telemedicine applications: mast". *International journal of technology assessment in health care* 28.01 (2012), pp. 44–51.

[132] D. Moher, S. Hopewell, K. F. Schulz, V. Montori, P. C. Gøtzsche, P. Devereaux, D. Elbourne, M. Egger, and D. G. Altman. "CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials". *Journal of clinical epidemiology* 63.8 (2010), e1–e37.

[133] M. Bhandari and E. H. Schemitsch. "Randomized trials: A brief history and modern perspective". *Techniques in Orthopaedics* 19.2 (2004), pp. 54–56.

[134] B. Brighton, M. Bhandari, P. Tornetta, D. T. Felson, et al. "Hierarchy of evidence: from case reports to randomized controlled trials." *Clinical orthopaedics and related research* 413 (2003), pp. 19–24.

[135] R. B. Haynes, J. Mukherjee, D. L. Sackett, D. W. Taylor, H. J. Barnett, and S. J. Peerless. "Functional Status Changes Following Medical or Surgical Treatment for Cerebral Ischemia: Results of the Extracranial-lntracranial Bypass Study". *JAMA* 257.15 (1987), pp. 2043–2046.

[136] A.-W. Chan, J. M. Tetzlaff, P. C. Gøtzsche, D. G. Altman, H. Mann, J. A. Berlin, K. Dickersin, A. Hróbjartsson, K. F. Schulz, W. R. Parulekar, et al. "SPIRIT 2013 explanation and elaboration: guidance for protocols of clinical trials". *Bmj* 346 (2013), e7586.

[137] M. Petticrew and H. Roberts. "Evidence, hierarchies, and typologies: horses for courses". *Journal of epidemiology and community health* 57.7 (2003), pp. 527–529.

[138] M. K. Zebis, L. L. Andersen, M. T. Pedersen, P. Mortensen, C. H. Andersen, M. M. Pedersen, M. Boysen, K. K. Roessler, H. Hannerz, O. S. Mortensen, et al. "Implementation of neck/shoulder exercises for pain relief among

industrial workers: a randomized controlled trial". *BMC musculoskeletal disorders* 12.1 (2011), p. 1.

[139] Y. Bai, D. Mo, L. Zhang, M. Boswell, and S. Rozelle. "The impact of integrating ICT with teaching: Evidence from a randomized controlled trial in rural schools in China". *Computers & Education* 96 (2016), pp. 1–14.

[140] A.-W. Chan, J. M. Tetzlaff, D. G. Altman, A. Laupacis, P. C. Gøtzsche, K. Krleža-Jerić, A. Hróbjartsson, H. Mann, K. Dickersin, J. A. Berlin, et al. "SPIRIT 2013 statement: defining standard protocol items for clinical trials". *Annals of internal medicine* 158.3 (2013), pp. 200–207.

[141] WHO. *WHO Trial Registration Data Set (Version 1.2.1)*. 2016. URL: `http://www.who.int/ictrp/network/trds/en/` (visited on 31/05/2016).

[142] P. Kadam and S. Bhalerao. "Sample size calculation". *International journal of Ayurveda research* 1.1 (2010), p. 55.

[143] B. K. Nayak. "Understanding the relevance of sample size calculation". *Indian journal of ophthalmology* 58.6 (2010), p. 469.

[144] I. Boutron, D. Moher, D. G. Altman, K. F. Schulz, and P. Ravaud. "Methods and processes of the CONSORT Group: example of an extension for trials assessing nonpharmacologic treatments". *Annals of Internal Medicine* 148.4 (2008), W–60.

[145] I. Boutron, D. Moher, D. G. Altman, K. F. Schulz, and P. Ravaud. "Extending the CONSORT statement to randomized trials of nonpharmacologic treatment: explanation and elaboration". *Annals of internal medicine* 148.4 (2008), pp. 295–309.

[146] K. F. Schulz, D. G. Altman, and D. Moher. "CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials". *BMC medicine* 8.1 (2010), p. 1.

[147] S. Hopewell, M. Clarke, D. Moher, E. Wager, P. Middleton, D. G. Altman, K. F. Schulz, C. Group, et al. "CONSORT for reporting randomised trials in journal and conference abstracts". *The Lancet* 371.9609 (2008), pp. 281–283.

[148] S. Hopewell, M. Clarke, D. Moher, E. Wager, P. Middleton, D. G. Altman, K. F. Schulz, C. Group, et al. "CONSORT for reporting randomized controlled trials in journal and conference abstracts: explanation and elaboration". *PLoS Med* 5.1 (2008), e20.

[149] T. C. Hoffmann, C. Erueti, and P. P. Glasziou. "Poor description of non-pharmacological interventions: analysis of consecutive sample of randomised trials" (2013).

[150] T. C. Hoffmann, P. P. Glasziou, I. Boutron, R. Milne, R. Perera, D. Moher, D. G. Altman, V. Barbour, H. Macdonald, M. Johnston, et al. "Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide". *Bmj* 348 (2014), g1687.

[151] K. Suresh. "An overview of randomization techniques: an unbiased assessment of outcome in clinical research". *Journal of human reproductive sciences* 4.1 (2011), p. 8.

[152] L. Thabane, L. Mbuagbaw, S. Zhang, Z. Samaan, M. Marcucci, C. Ye, M. Thabane, L. Giangregorio, B. Dennis, D. Kosa, et al. "A tutorial on sensitivity analyses in clinical trials: the what, why, when and how". *BMC medical research methodology* 13.1 (2013), p. 92.

[153] C. for Medicinal Products for Human Use et al. "Guideline on missing data in confirmatory clinical trials". *London: European Medicines Agency* (2010).

[154] J. L. Schafer and J. W. Graham. "Missing data: our view of the state of the art." *Psychological methods* 7.2 (2002), p. 147.

[155] R. J. Little, R. D'Agostino, M. L. Cohen, K. Dickersin, S. S. Emerson, J. T. Farrar, C. Frangakis, J. W. Hogan, G. Molenberghs, S. A. Murphy, et al. "The prevention and treatment of missing data in clinical trials". *New England Journal of Medicine* 367.14 (2012), pp. 1355–1360.

[156] A. R. T. Donders, G. J. van der Heijden, T. Stijnen, and K. G. Moons. "Review: a gentle introduction to imputation of missing values". *Journal of clinical epidemiology* 59.10 (2006), pp. 1087–1091.

[157] E. Boulton, H. Hawley-Hague, B. Vereijken, A. Clifford, N. Guldemond, K. Pfeiffer, A. Hall, F. Chesani, S. Mellone, A. Bourke, et al. "Developing the FARSEEING Taxonomy of Technologies: Classification and description of technology use (including ICT) in falls prevention studies". *Journal of Biomedical Informatics* 61 (2016), pp. 132–140.

[158] U. Flick. *An introduction to qualitative research*. Sage, 2009.

[159] K. Steiner. "Interview-En introduktion til det kvalitative forskningsinterview". *Hans Reitzels Forlag* (1997).

[160] S. Kvale. *Doing interviews*. Sage, 2008.

[161] B. G. Glaser and A. L. Strauss. *The discovery of grounded theory: Strategies for qualitative research*. Transaction publishers, 2009.

[162] B. DiCicco-Bloom and B. F. Crabtree. "The qualitative research interview". *Medical education* 40.4 (2006), pp. 314–321.

[163] R. Kenny, L. Z. Rubenstein, M. E. Tinetti, K. Brewer, K. A. Cameron, L. Capezuti, D. P. John, S. E. Lamb, F. Martin, P. H. Rockey, et al. "Summary of the updated American Geriatrics Society/British Geriatrics Society clinical practice guideline for prevention of falls in older persons". *Journal of the American Geriatrics Society* 59.1 (2011), pp. 148–157.

[164] A. C. Tiedemann, S. M. Murray, B. Munro, and S. R. Lord. "Hospital and non-hospital costs for fall-related injury in community-dwelling older people". *New South Wales public health bulletin* 19.10 (2008), pp. 161–165.

[165] A. Taylor, N. Cable, G. Faulkner, M. Hillsdon, M. Narici, and A. Van Der Bij. "Physical activity and older adults: a review of health benefits and the effectiveness of interventions". *Journal of sports sciences* 22.8 (2004), pp. 703–725.

[166] G. N. Yannakakis, H. H. Lund, and J. Hallam. "Modeling children's entertainment in the playware playground". *Computational Intelligence and Games, 2006 IEEE Symposium on*. IEEE. 2006, pp. 134–141.

[167] R. A. Bell. "Aerobic fitness, physical function and falls among older people: a prospective study" (2008).

[168] R. C. Isles, N. L. Choy, M. Steer, and J. C. Nitz. “Normal values of balance tests in women aged 20–80”. *Journal of the American Geriatrics Society* 52.8 (2004), pp. 1367–1372.

[169] D. J. Rose, C. J. Jones, and N. Lucchese. “Predicting the probability of falls in community-residing older adults using the 8-foot up-and-go: a new measure of functional mobility”. *Journal of Aging and Physical Activity* 10.4 (2002), pp. 466–475.

[170] C. J. Jones, R. E. Rikli, and W. C. Beam. “A 30-s chair-stand test as a measure of lower body strength in community-residing older adults”. *Research quarterly for exercise and sport* 70.2 (1999), pp. 113–119.

[171] L. Vereeck, F. Wuyts, S. Truijen, and P. Van de Heyning. “Clinical assessment of balance: normative data, and gender and age effects”. *International journal of audiology* 47.2 (2008), pp. 67–75.

[172] Nintendo. *Nintendo Wii Balance Board*. Japan, 2007.

[173] I. H. Stevenson, H. L. Fernandes, I. Vilares, K. Wei, and K. P. Körding. “Bayesian integration and non-linear feedback control in a full-body motor task”. *PLoS Comput Biol* 5.12 (2009), e1000629.

[174] F. Sgrò, G. Monteleone, M. Pavone, and M. Lipoma. “Validity analysis of Wii Balance Board versus baropodometer platform using an open custom integrated application”. *AASRI Procedia* 8 (2014), pp. 22–29.

[175] L. M. Taylor, R. Maddison, L. A. Pfaeffli, J. C. Rawstorn, N. Gant, and N. M. Kerse. “Activity and energy expenditure in older people playing active video games”. *Archives of physical medicine and rehabilitation* 93.12 (2012), pp. 2281–2286.

[176] H. H. Lund. “Playware Research–Methodological Considerations”. *Journal of Robotics, Networks and Artificial Life* 1.1 (2014), pp. 23–27.

[177] L. Vgotsky. *Mind in society: The development of higher mental processes*. 1978.

[178] C. B. Nielsen and H. H. Lund. “Adapting playware to rehabilitation practices”. *International Journal of Computer Science in Sport* 11.1 (2012).

[179] C. Sherrington, J. C. Whitney, S. R. Lord, R. D. Herbert, R. G. Cumming, and J. C. Close. "Effective exercise for the prevention of falls: a systematic review and meta-analysis". *Journal of the American Geriatrics Society* 56.12 (2008), pp. 2234–2243.

[180] S. R. Lord, H. B. Menz, and A. Tiedemann. "A physiological profile approach to falls risk assessment and prevention". *Physical therapy* 83.3 (2003), pp. 237–252.

[181] N. B. Alexander, D. R. Dengel, R. J. Olson, and K. M. Krajewski. "Oxygen-uptake (VO2) kinetics and functional mobility performance in impaired older adults". *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 58.8 (2003), pp. M734–M739.

[182] M. E. Cress and M. Meyer. "Maximal voluntary and functional performance needed for independence in adults aged 65 to 97 years". *Physical therapy* 83.1 (2003), pp. 37–48.

[183] O. F. Prevention and O. S. Panel. "Guideline for the prevention of falls in older persons". *Journal of the American Geriatrics Society* 49.5 (2001), pp. 664–672.

[184] D. Wollersheim, M. Merkes, N. Shields, P. Liamputtong, L. Wallis, F. Reynolds, and L. Koh. "Physical and psychosocial effects of Wii video game use among older women". *International Journal of Emerging Technologies and Society* 8.2 (2010), p. 85.

[185] W. Peng, J.-H. Lin, and J. Crouse. "Is playing exergames really exercising? A meta-analysis of energy expenditure in active video games". *Cyberpsychology, Behavior, and Social Networking* 14.11 (2011), pp. 681–688.

[186] M. J. Taylor, D. McCormick, R. Impson, T. Shawis, and M. Griffin. "Activity Promoting Gaming Systems in Exercise and Rehabilitation." *Journal of rehabilitation research and development* 48.10 (2011), pp. 1171–1186.

[187] J. Nitz, S. Kuys, R. Isles, and S. Fu. "Is the Wii Fit^{TM} a new-generation tool for improving balance, health and well-being? A pilot study". *Climacteric* 13.5 (2010), pp. 487–491.

[188] J.-A. Gil-Gómez, R. Lloréns, M. Alcañiz, and C. Colomer. “Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation: a pilot randomized clinical trial in patients with acquired brain injury”. *Journal of neuroengineering and rehabilitation* 8.1 (2011), p. 1.

[189] G. Saposnik, R. Teasell, M. Mamdani, J. Hall, W. McIlroy, D. Cheung, K. E. Thorpe, L. G. Cohen, M. Bayley, S. O. R. C. (W. Group, et al. “Effectiveness of virtual reality using Wii gaming technology in stroke rehabilitation a pilot randomized clinical trial and proof of principle”. *Stroke* 41.7 (2010), pp. 1477–1484.

[190] B. Lange, S. Flynn, R. Proffitt, C.-Y. Chang, and A. “Skip” Rizzo. “Development of an interactive game-based rehabilitation tool for dynamic balance training”. *Topics in stroke rehabilitation* 17.5 (2010), pp. 345–352.

[191] J. Wiemeyer and A. Kliem. “Serious games in prevention and rehabilitation—a new panacea for elderly people?” *European Review of Aging and Physical Activity* 9.1 (2012), pp. 41–50.

[192] A. Barnett, B. Smith, S. R. Lord, M. Williams, and A. Baumand. “Community-based group exercise improves balance and reduces falls in at-risk older people: a randomised controlled trial”. *Age and ageing* 32.4 (2003), pp. 407–414.

[193] S. R. Lord, J. A. Ward, P. Williams, and M. Strudwick. “The Effect of a 12-Month Exercise Trial on Balance, Strength, and Falls in Older Women: A Randomized Controlled Trial”. *Journal of the American Geriatrics Society* 43.11 (1995), pp. 1198–1206.

[194] S. R. Lord, D. G. Lloyd, M. Nirui, J. Raymond, P. Williams, and R. A. Stewart. “The effect of exercise on gait patterns in older women: a randomized controlled trial”. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 51.2 (1996), pp. M64–M70.

[195] *Tiles games*. 2014. URL: `https://www.youtube.com/channel/UCiOczIy1x5FXCyqM_eukHGw` (visited on 31/05/2016).

[196] R. B. Lopopolo, M. Greco, D. Sullivan, R. L. Craik, and K. K. Mangione. "Effect of therapeutic exercise on gait speed in community-dwelling elderly people: a meta-analysis". *Physical Therapy* 86.4 (2006), pp. 520–540.

[197] S. E. Hardy, S. Perera, Y. F. Roumani, J. M. Chandler, and S. A. Studenski. "Improvement in usual gait speed predicts better survival in older adults". *Journal of the American Geriatrics Society* 55.11 (2007), pp. 1727–1734.

[198] R. DiBrezzo, B. B. Shadden, B. H. Raybon, and M. Powers. "Exercise intervention designed to improve strength and dynamic balance among community-dwelling older adults". *J Aging Phys Act* 13.2 (2005), pp. 198–209.

[199] T. E. Shubert. "Evidence-based exercise prescription for balance and falls prevention: a current review of the literature". *Journal of geriatric physical therapy* 34.3 (2011), pp. 100–108.

[200] H. H. Lund. "Modular interactive tiles for rehabilitation: evidence and effect". *Proceedings of the 10th WSEAS international conference on Applied computer science, ACS*. Vol. 10. 2010, pp. 520–525.

[201] J. D. Jessen and C. Jessen. "What games do" (2014).

[202] P. Dourish. *Where the action is: the foundations of embodied interaction*. MIT press, 2004.

[203] A. Yaneva. "Making the social hold: Towards an Actor-Network theory of design". *Design and Culture* 1.3 (2009), pp. 273–288.

[204] M. Cypher and I. Richardson. "An actor-network approach to games and virtual environments". *Proceedings of the 2006 international conference on Game research and development*. Murdoch University. 2006, pp. 254–259.

[205] K. P. Kallio, F. Mayra, and K. Kaipainen. "At least nine ways to play: Approaching gamer mentalities". *Games and Culture* (2010), p. 1555412010391089.

[206] L. Phillips and U. Plesner. *Researching Virtual Worlds: Methodologies for Studying Emergent Practices*. Vol. 14. Routledge, 2013.

[207] S. Giddings. "Events and collusions: A glossary for the microethnography of video game play". *Games and Culture* (2008).

[208] O. Hanseth and E. Monteiro. "Understanding information infrastructure". *Unpublished Manuscript, Retrieved on 6th September from http://heim. ifi. uio. no/˜ oleha/Publications/bok. pdf* (1998).

[209] B. J. Kraal. "Actor-network inspired design research: Methodology and reflections" (2007).

[210] J. Rhodes. "Using actor-network theory to trace an ICT (telecenter) implementation trajectory in an African women's micro-enterprise development organization". *Information Technologies & International Development* 5.3 (2009), pp–1.

[211] J. P. Spradley. "Participant observation" (1980).

[212] P. Atkinson, M. Hammersley, et al. "Ethnography and participant observation". *Handbook of qualitative research* 1.23 (1994), pp. 248–261.

[213] S. Anselm and C. Juliet. *Basics of qualitative research: grounded theory procedures and techniques*. 3rd ed. Sage Publications, London, 208.

[214] R. Dankert. *Using Actor-Network Theory (ANT) doing research*. URL: `http://ritskedankert.nl/publicaties/2010/-item/using-actor-network-theory-ant-doing-research` (visited on 31/10/2013).

[215] R. Nimmo. "Actor-network theory and methodology: Social research in a more-than-human world". *Methodological Innovations Online* 6.3 (2011), pp. 108–119.

[216] C. Jessen. "Interpretive communities: The reception of computer games by children and the young". *Retrieved August* 9 (1998), p. 2004.

[217] J. Piaget and B. Inhelder. *The psychology of the child*. Basic Books, 2008.

[218] L. S. Vygotsky. "Play and its role in the mental development of the child". *Soviet psychology* 5.3 (1967), pp. 6–18.

[219] G. Bateson et al. "The message," This is play."" *Group processes* 2 (1956), pp. 145–241.

[220] H. Pedersen. *Prevention of falls among the elderly are deficient (Original Danish title: Forebyggelse af fald blandt ældre er mangelfuld)*. 2012. URL: `http://mags.datagraf.dk/magasinsundhed/19/`.

[221] A. G. Ershow, C. M. Peterson, W. T. Riley, A. S. Rizzo, and B. Wansink. “Virtual reality technologies for research and education in obesity and diabetes: research needs and opportunities”. *Journal of diabetes science and technology* 5.2 (2011), pp. 212–224.

[222] U. S. D. of Health. *Physical activity and health: a report of the Surgeon General*. diane Publishing, 1996.

[223] R. C. Plotnikoff, S. A. Costigan, N. D. Karunamuni, and D. R. Lubans. “Community-based physical activity interventions for treatment of type 2 diabetes: a systematic review with meta-analysis”. *Front Endocrinol (Lausanne)* 4.3 (2013).

[224] K. M. Nelson, G. Reiber, and E. J. Boyko. “Diet and exercise among adults with type 2 diabetes findings from the third national health and nutrition examination survey (NHANES III)”. *Diabetes care* 25.10 (2002), pp. 1722–1728.

[225] A. L. Dunn, R. E. Andersen, and J. M. Jakicic. “Lifestyle physical activity interventions: History, short-and long-term effects, and recommendations”. *American journal of preventive medicine* 15.4 (1998), pp. 398–412.

[226] C. J. Greaves, K. E. Sheppard, C. Abraham, W. Hardeman, M. Roden, P. H. Evans, and P. Schwarz. “Systematic review of reviews of intervention components associated with increased effectiveness in dietary and physical activity interventions”. *BMC public health* 11.1 (2011), p. 1.

[227] J. Daly, A. P. Sindone, D. R. Thompson, K. Hancock, E. Chang, and P. Davidson. “Barriers to participation in and adherence to cardiac rehabilitation programs: a critical literature review”. *Progress in cardiovascular nursing* 17.1 (2002), pp. 8–17.

[228] G. C. L. de Groot and L. Fagerström. “Older adults’ motivating factors and barriers to exercise to prevent falls”. *Scandinavian Journal of Occupational Therapy* 18.2 (2011), pp. 153–160.

[229] D. Health and M. Authority. *Recommendations on Physical Activity for the elderly (+65 years) (Original Danish title: Anbefalinger om fysisk aktivitet*

til ældre (+65 år)). 2012. URL: `https://sundhedsstyrelsen.dk/da/sundhed/fysiskaktivitet/anbefalinger/aeldre`.

[230] D. Brandt, D. J. Christensen, and H. H. Lund. "ATRON robots: versatility from self-reconfigurable modules". *Mechatronics and Automation, 2007. ICMA 2007. International Conference on*. IEEE. 2007, pp. 26–32.

[231] N. D. Carter, P. Kannus, and K. Khan. "Exercise in the prevention of falls in older people". *Sports Medicine* 31.6 (2001), pp. 427–438.

[232] S. E. Lamb, C. Becker, L. D. Gillespie, J. L. Smith, S. Finnegan, R. Potter, K. Pfeiffer, et al. "Reporting of complex interventions in clinical trials: development of a taxonomy to classify and describe fall-prevention interventions". *Trials* 12.1 (2011), p. 125.

[233] H. H. Lund and C. B. Nielsen. "Modularity for modulating exercises and levels-observations from cardiac, stroke, and COLD patients therapy". *Ubiquitous Robots and Ambient Intelligence (URAI), 2011 8th International Conference on*. IEEE. 2011, pp. 253–258.

[234] S. B. N. Komiteen for Sundhedsoplysning. *8 anbefalinger til forebyggelse af ældres faldulykker - den gode kommunale model*. 2010. URL: `http://goo.gl/PMRR9t` (visited on 01/06/2016).

[235] A. Shumway-Cook, M. A. Ciol, J. Hoffman, B. J. Dudgeon, K. Yorkston, and L. Chan. "Falls in the Medicare population: incidence, associated factors, and impact on health care". *Physical therapy* 89.4 (2009), pp. 324–332.

[236] J. A. Rizzo, R. Friedkin, C. S. Williams, J. Nabors, D. Acampora, and M. E. Tinetti. "Health care utilization and costs in a Medicare population by fall status". *Medical care* 36.8 (1998), pp. 1174–1188.

[237] P. A. Logan, C. A. Coupland, J. R. Gladman, O. Sahota, V. Stoner-Hobbs, K. Robertson, V. Tomlinson, M. Ward, T. Sach, and A. J. Avery. "Community falls prevention for people who call an emergency ambulance after a fall: randomised controlled trial". *Bmj* 340 (2010), p. c2102.

[238] T. E. Kennedy. "The prevention of falls in later life". *DMB. Spec. suppl. ser., Gerontology* (1987).

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